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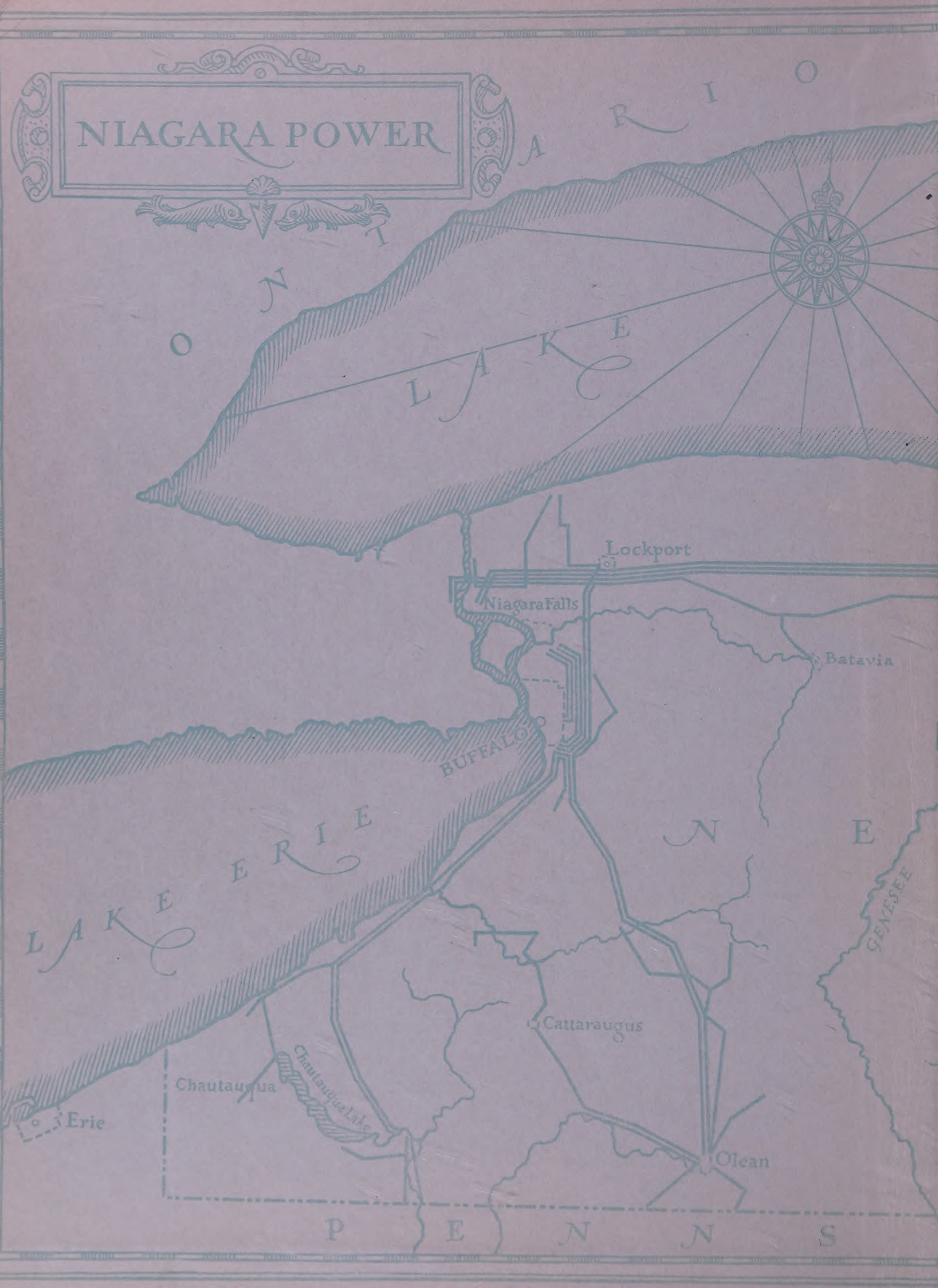
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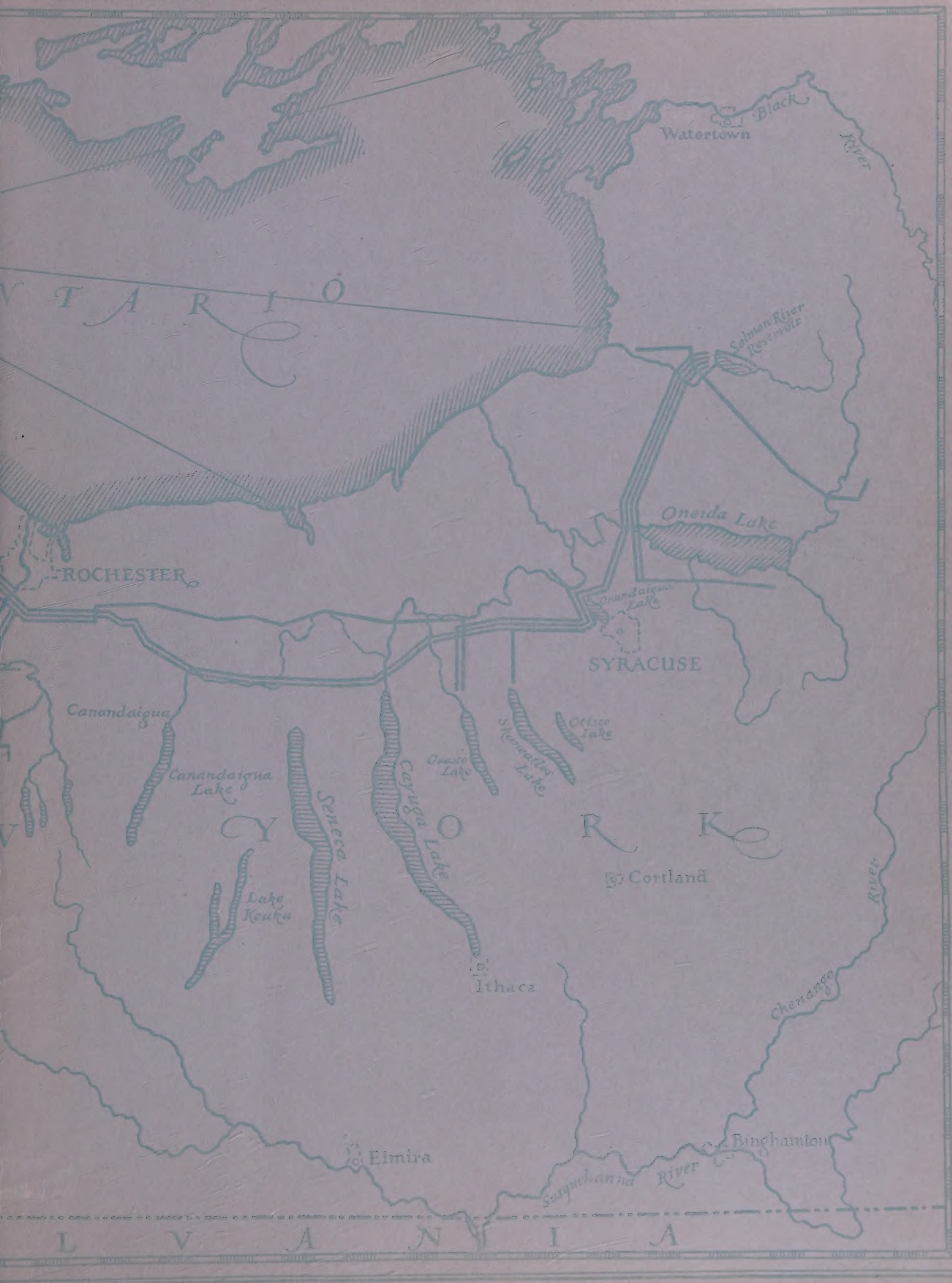
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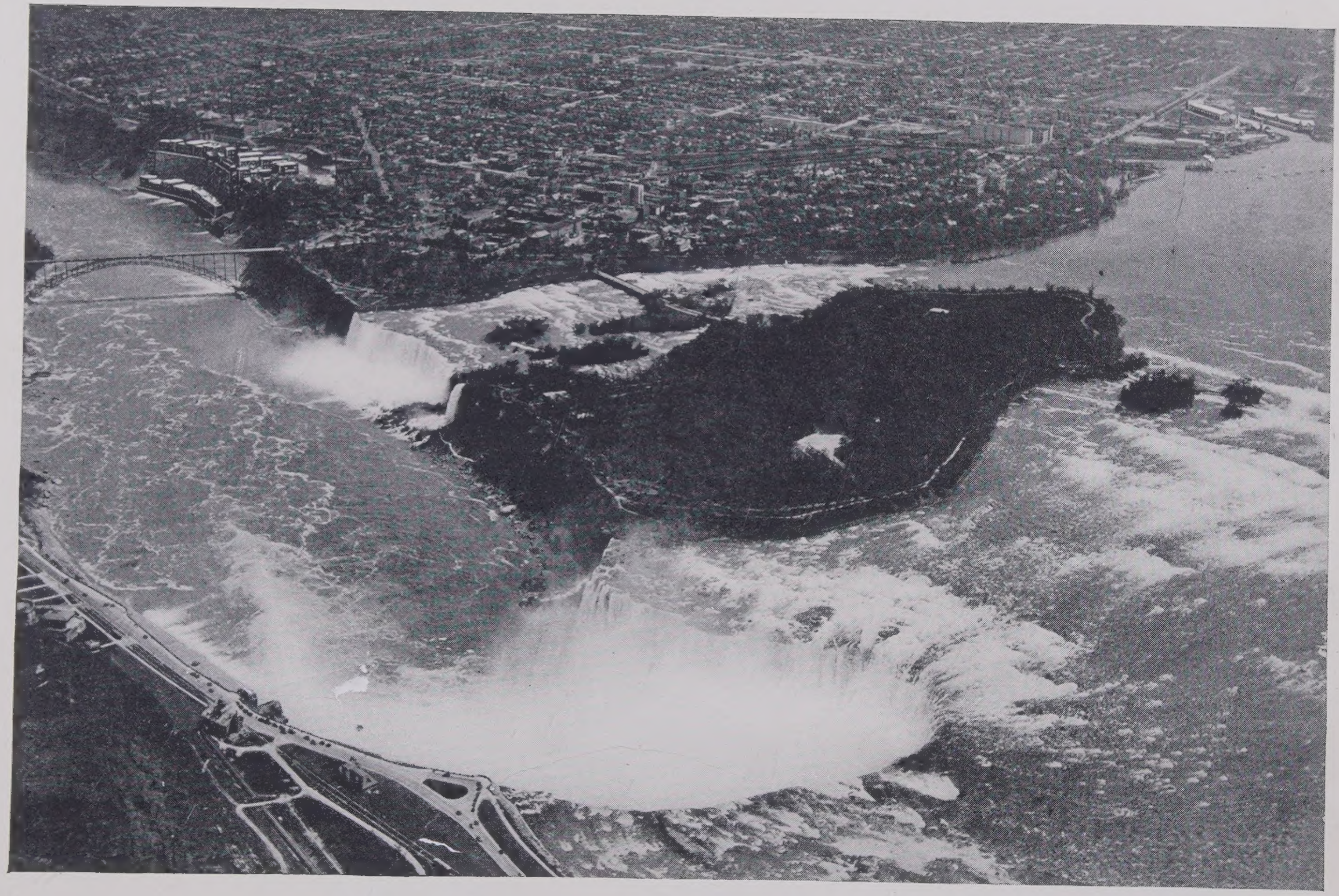

Aeroplane View of Niagara Falls and Power-plants, 1926

City of Niagara (upper center); Goat Island (middle center); Main Generating Plant, The Niagara Falls Power Company (upper left); Reserve Plant, The Niagara Falls Power Company (upper right)

NIAGARA POWER

HISTORY OF

THE NIAGARA FALLS POWER COMPANY

1886–1918

EVOLUTION OF ITS

CENTRAL POWER STATION *and* ALTERNATING CURRENT SYSTEM

[IN TWO VOLUMES]

VOLUME II

CONSTRUCTION AND OPERATION

By

EDWARD DEAN ADAMS

M.A., M.S., LL.D.

JOHN FRITZ MEDALIST

MCMXXVI

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CONSTRUCTION AND OPERATION

REVIEWS AND REFLECTIONS

Volume Two

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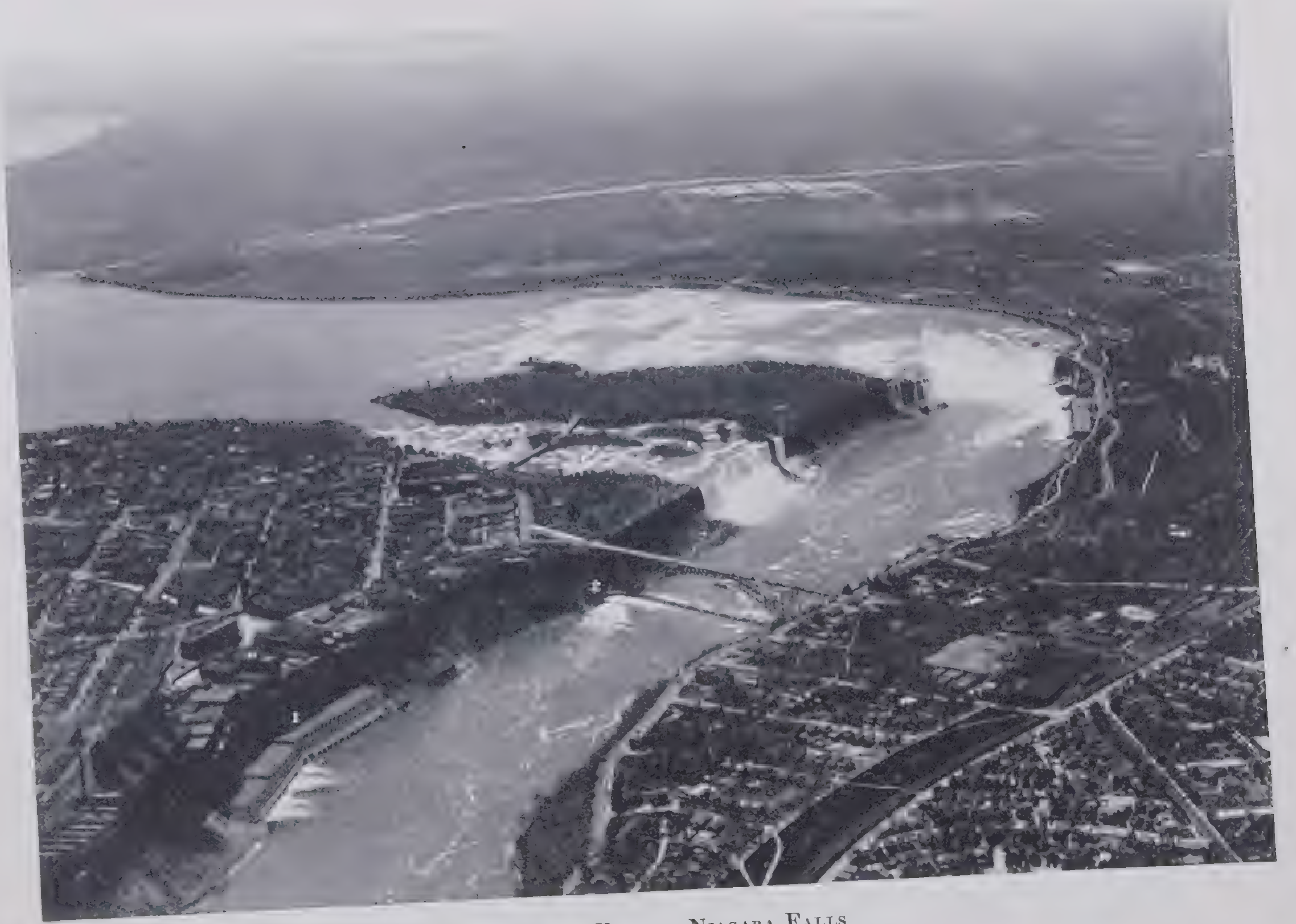
CONSTRUCTION AND OPERATION

TUNNEL, INLET, AND WHEEL-PIT SLOT

CHAPTER XVII



Aeroplane View of Niagara Falls

1. *Main Generating Plant, The Niagara Falls Power Company,* MCMXVIII
2. *Portal of Discharge Tunnel from Power-houses Numbers One and Two*

TUNNEL, INLET, AND WHEEL-PIT SLOT

CHAPTER XVII

PRE-CONSTRUCTION DEVELOPMENTS OF EVERSHED TUNNEL PROJECT

THE original special act[1] of incorporation by the State of New York authorized the construction, maintenance and operation, in connection with the Niagara River, of "a hydraulic tunnel or subterranean sewer for the public use of sewerage and drainage, as hereinafter specified, and for furnishing hydraulic power for manufacturing purposes," conditioned, with other provisions, upon permitting the villages to use the tunnel or sewer for the purpose of draining or sewering the villages upon reasonable rates, and such conditions as might be agreed upon. The company thus originally chartered as the Niagara River Hydraulic Tunnel, Power and Sewer Company, became the so-called Gaskill[2] company, that passed, by the sale of its entire capital stock, with the Evershed plan for Niagara power development it had acquired, into the ownership of The Cataract Construction Company.

Careful and prolonged consideration of the original Evershed plan of 1886 brought the "money subscribers," under the guidance of their board of engineers, to the following decision, in the early part of 1890.

To proceed with the enterprise:

1. By the construction of a discharge tunnel of about 1 mile in length as the first section of the long tunnel designed;
2. By the further study of methods of utilizing the waters of the river for power.

In February, 1890, The Cataract Construction Company was formally requested by its stockholders to proceed with the project, for which ample funds had been subscribed under their agreement of January 17, 1890.

The quantity element again came into the questions under consideration, and as pioneers, the directors made decisions according to their best judgment, but only after counselling with the most experienced hydraulic engineers at home and abroad. No experience from experiments or practise was extant with water being discharged through a tunnel of so great a diameter as 24 feet. The head forcing water through the tunnel was only about 50 feet more or less. No empirical formula could be depended upon to give reliable results under such untried conditions.

The numerous deeds, constituting the right-of-way more than a mile long and for the construction of the first tunnel, granted authority to excavate and maintain a tunnel at a depth of not less than 100 feet, through, across and under the lots located in the tunnel line surveyed in the village of Niagara Falls.

---

[1] Section 10, Chapter 83, Laws of New York, 1886.

[2] Named after Col. Charles B. Gaskill, its president.

The board of engineers took up its work actively. The contour survey and map, on a large scale, of the company's lands, including those under water and the right-of-way and franchise privileges, were sufficiently advanced in March, 1890, to permit the location of a tunnel, then authorized, 7000 feet in length, 18 feet wide and 29 feet high, at a grade of 7 feet in 1000 feet, with its invert upon entering the river 14½ feet, one half its total height, below ordinary river level. Chief Engineer Sellers and Consulting Engineer John Bogart assured the directors of the cataract company that the proposed plans for construction met their approval, that there were no unusual difficulties anticipated for the work, and that the estimates were ample.

TUNNEL CONSTRUCTION BEGUN

In September, 1890, Clemens Herschel, hydraulic engineer, visited London for a conference with Chief Engineer Coleman Sellers, Prof. William Cawthorne Unwin, secretary of the International Niagara Commission, and George F. Deacon, hydraulic engineer of Liverpool, with reference to the hydraulic system of the Niagara company. After a full exchange of views and experiences, with detailed explanations of the local conditions at Niagara and the probable requirements there in the future, the form, grade and location of the tunnel were agreed upon unanimously. Upon Mr. Herschel's return, the tunnel contract was let with provisions for modification of the original plans, should the company so desire during construction. The construction of the tunnel commenced October 4, 1890, and was carried forward upon the plans prepared therefor by the board of engineers of the cataract company, with the co-operation and approval of the hydraulic engineer.

Mr. Herschel called attention, in his first report on this enterprise, to his belief that the plans, if carried out prudently, would be profitable, but not right away. His suggestions were for economy in capital expenditure. His conservatism was shown by his designs of units of development that could be increased or duplicated as desired to meet commercial demands.

METHOD OF CENTRAL POWER PRODUCTION PROPOSED

While the tunnel work continued from five headings, with favorable progress, the study of new designs to modify the Evershed plan was carried on, each succeeding sketch reducing that system's tunnels, water-inlets and wheel-pits, until, eventually, soon after the sessions of the International Niagara Commission, in February, 1891, the board of engineers abandoned the long established American method of each manufacturer generating his own power, and adopted the new system of a central power station, where alone all the power was to be created and distributed by one or more methods of electric, compressed air or water that might be selected as best adapted to the needs of the company's customers.

The board of engineers, as well as some of the officers and directors of the company, were loath to make so radical a departure from long established custom for what seemed both new and striking, understood by few, but endorsed by scientific practitioners of the highest authority, and demonstrated by European examples of application, that in facility and economy indicated a new era in applied mechanics and that stirred the world of manufacturers by its promises.

The managers of the cataract company realized that it would require a prolonged period of investigation and familiarity with the details of electric transmission to overcome prejudice and to induce the investment of other people's capital in factories designed to use that system. The directors had investigated the international situation in this regard and deliberatively decided, in effect, to meet whatever might be the necessary delay, in preference to the adoption of prevailing systems, that were deteriorating by use and would eventually be replaced, in their opinion, by the new and more economical methods of power production and distribution.

It was recognized that the old-time manufacturer hesitated to give up his personal supervision of his own supply of power, however crudely and inefficiently applied, and to take in its place a comparatively delicate piece of machinery he did not understand, that was activated by a wire, the operation of which was startling to hear, dazzling to see, and dangerous to touch.

In new constructions for the use of power the new system compelled consideration by the rapidity of its adoption in Europe and at home. Owners of existing plants in most countries were not disposed to abandon well-tried machinery that had been profitably operated, and could still be depended upon, except in special cases of drought or irregular delivery of fuel, that were understood.

As to the continuity of electrical power, created and distributed at a distance by strangers over whom the consumer had no authority or supervision and for whose action, in a failure of supply when most needed, he had no remedy nor any responsibility except to his own employees and his own profit and loss account, the possible customer was skeptical and preferred to wait until his machinery required replacement; then he would know more about the matter, or perhaps his successors would, and they and others would have the experience by which they could profit in deciding upon their future course.

As it would be preferable, from the salesman's point of view, to transmit the power to Buffalo and its 256,000 population, and there to demonstrate its continuity, its regularity and comparative economy, and its facilities in use, rather than to await a market at Niagara, the transmission to Buffalo and a plan for its distribution there, as well as locally at Niagara, became an important part of the program of construction.

Ten of the company's officers and engineers had visited Switzerland, France, Italy and England on one or more occasions each in a period of about six months, where they made the personal acquaintance of the foremost hydraulic and electric ingénieurs constructeurs and through their courteous hospitality became familiar with the latest and most important installations of hydraulic power development and its transmission, and learned, by inspection of plans, of still larger units of prime movers that were in preparation for group operation in central stations of hydro-electric power distribution.

Because of the great expense and the long period of time required for construction under the Evershed plan and the comparative scarcity of local industries and inhabitants (about 5000 population only in 1890 in the village of Niagara Falls), the sole elements of this plan believed to be useful for the enterprise were about one-third of the main tunnel, and one short water-inlet. All else was considered impracticable and abandoned except that provision was made incidentally for a short side tunnel[1] as a discharge for possible future wheel-pits in the land on the north side of Buffalo Avenue that could be readily supplied with water from the inlet-canal; also for a water-inlet on the western side of the inlet-canal, near its mouth, under the terms of a lease[2] made with the Niagara Falls Paper Company, authorizing it to draw a quantity of water to the extent of about 8000 horse-power and to discharge the same by a private side tunnel into the main tail-race, or discharge tunnel. In both instances it was expected that the lessee-manufacturer would provide and supervise its own machinery for the utilization of the water and its power. This paper company lease was the first contract for water-power and the only agreement by the company based upon the old system of "mill over a wheel-pit," where the lessee owned and controlled its machinery and the power company furnished the water and the tunnel facilities for its discharge after use.

The development of a simple hydraulic system, essentially different from the complex plan of Evershed, under serious consideration from January, 1890, was practically determined when construction commenced on a single tail-race tunnel, October 4, 1890, and later on a single water inlet-canal and thereafter on a single wheel-pit slot, August 31, 1891.

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[1] Not utilized in 1927.

[2] Changed later to contract for electric power in place of previous hydraulic method.

There were well understood mechanical devices for the transmission of power for short distances for local uses by shaft and rope or cable, and for comparatively long distances as well as local distribution, by the systems then occasionally in use, by water, air and direct-current electricity, all of which forms of power could be advantageously developed and distributed from a central station.

The International Niagara Commission received carefully prepared plans of all these methods that were submitted for consideration in the award of prizes and bonuses which were intended as expressions of authoritative commendation for application to the solution of the problem of developing the power of Niagara River.

Mass production, wide transmission and minute distribution expressed the purpose of the organization represented by The Cataract Construction Company in its plans for the utilization of the waters of Niagara.

SUCCESSIVE MODIFICATIONS OF EVERSHED PLAN

The only important feature of the Evershed plan that was finally adopted was the idea of a tunnel, from the vicinity of Port Day to the lower river, and this was materially changed with respect to its form, size, grade and other particulars.

The 3½ miles of tunnel has been reduced to 6700 feet; the twelve water-inlets were reduced to a single water-inlet or canal; instead of 238 wheel-pits, there is one wheel-pit slot on each side of the inlet; and in lieu of 238 units of 500 horse-power each, there have been assembled 5000 horse-power units in two power-houses of generation and distribution, of 100,000 horse-power total production.

The following plans show, in brief outlines, first the Evershed plan of 1886, and then the successive changes that were suggested, by which the reader can see what efforts were made, in the interest of economy, in construction and efficiency in operation and maintenance, to simplify the project that finally resulted as described in the Plan Number XII herein that shows the location of the tunnel and canal as constructed.

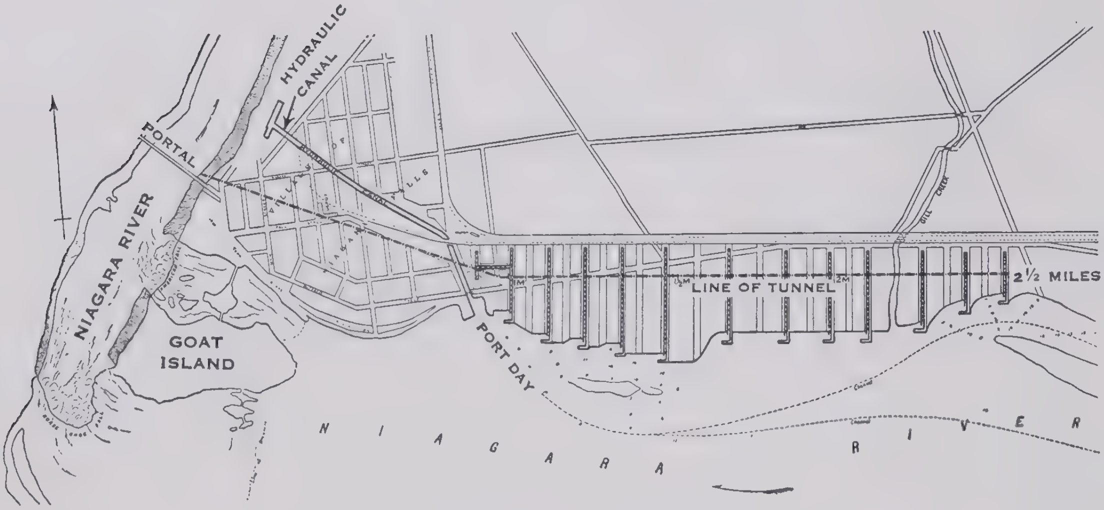
NIAGARA POWER

THE EVERSHED PLAN

OF 1886

POWER DEVELOPMENT AT NIAGARA FALLS ACQUIRED BY THE CATARACT CONSTRUCTION COMPANY WHEN IT PURCHASED THE CONTROL AND OWNERSHIP OF THE NIAGARA RIVER HYDRAULIC TUNNEL, POWER AND SEWER COMPANY

PLAN NUMBER I



Evershed Map of Mill-sites

Main tunnel, 2½ miles to river discharge. 12 inlet-canals, with transverse discharge tunnels from 238 mill-sites, each with wheel-pits of 500 horse-power capacity.

The enormous expense of excavating and possible lining, of these tunnels, canals and wheel-pits, about 6 miles of total construction, with comparatively no important industry then established at Niagara Falls prompted the rejection of the general plan.

The cost in time and money of factory construction was also prohibitive. Why should such industries move to Niagara? Whence the income to provide interest on the cost of tunnels, waterways, etc.?

The most likely newcomers were those who had fire insurance money to use in rebuilding or for new industries seeking locations that promised cheap power and transportation facilities.

The expenses of maintenance of such hydraulic systems were not favorable, at least in dealing with ice problems as they would naturally arise in the use of many shallow water intakes from the river's bank.

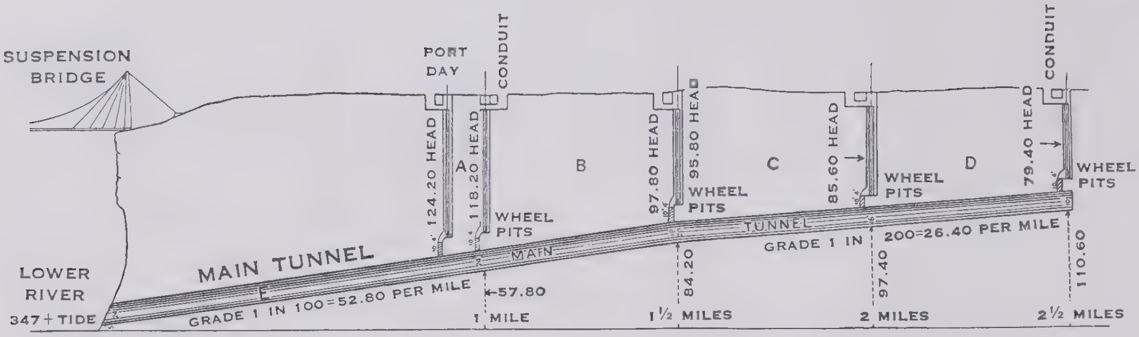
Under the guidance of Chief Engineer Coleman Sellers and his staff of engineers, each recognized as experienced and expert in his specialty, the hydraulic system of the company was formulated by molding the design of Thomas Evershed into the unique physical conditions prevailing and in conformity to the latest evidences of science and engineering that the officers of the company gathered abroad in addition to those obtained from the proceedings of the International Niagara Commission in London in 1891.

The numerous changes in the Evershed design were made progressively; each change suggested was drawn out and carefully considered; the single steps were gradually approved, being recognized as reasonable, logical and economical; compared with the plan constructed the changes from the Evershed plan were radical; the long used wheel-pit for each mill using the power had been abandoned for a vision of united strength in power development.

The pamphlet of 1886, entitled "Water Power at Niagara to be Successfully Utilized," issued by the Niagara River Hydraulic Tunnel, Power and Sewer Company, describes briefly this plan, over the names of the officers of that company, including that of its engineer, Thomas Evershed, whose report addressed to the president and trustees of the company, dated Rochester, July 1, 1886, contains his suggestions of a plan for the construction of a town plat or arrangement of lots, streets, mill-races, wharves and railroad tracks above ground on the bank of the Niagara River above Port Day, for the purpose of forming a town composed wholly of mills, factories and workshops, to be operated by the waters of Niagara River by means of turbine wheels or other devices and of main and lateral tunnels, an average of about 100 feet below ground, which should serve as tail-races for the factories and workshops.

A plan showing heads of water-wheels every half-mile formed a part of the pamphlet and are indicated on the following plans:

PLAN NUMBER II



Elevation Showing Heads on Water-wheels Every Half Mile, and Number of Powers Available of 500 Horse-power Each

A. Average head 120 feet
20 mills of 500 horse-power each
10,000 horse-power use 980 cubic feet per second.

B. Average head 107 feet
120 mills of 500 horse-power each
60,000 horse-power use 6580 cubic feet per second.

C. Average head of 90 feet
50 mills of 500 horse-power each
25,000 horse-power use 3260 cubic feet per second.

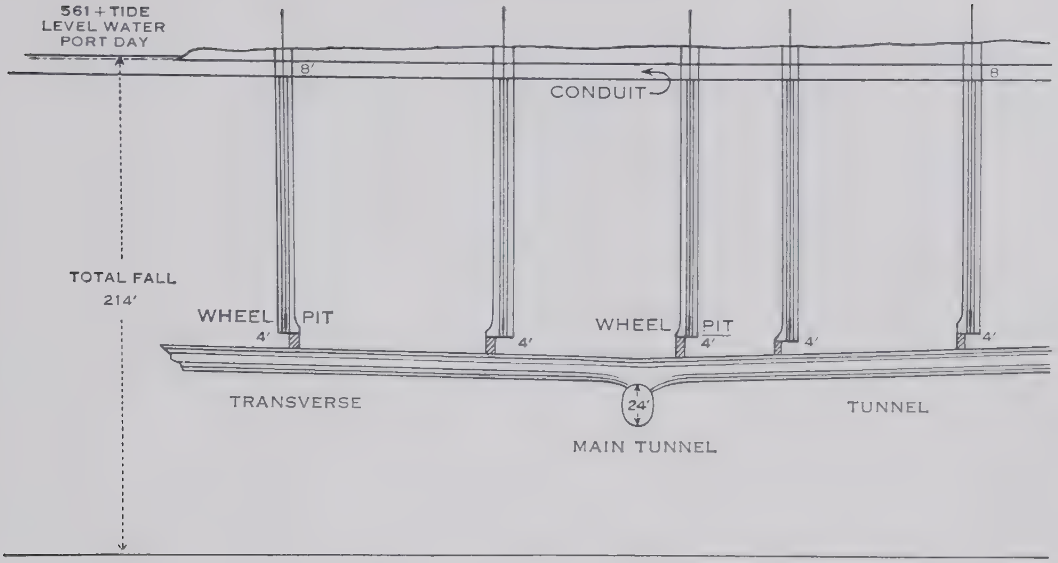
D. Average head 81 feet
48 mills of 500 horse-power each
24,000 horse-power use 3480 cubic feet per second.

E. Grade 1 in 100 = 52.80 per mile for 1½ miles
Grade 1 in 200 = 26.40 per mile for 1 mile.

Discharge 864,000 cubic feet per minute (Darcy)
14,400 per second
861,000 cubic feet per minute (Kutter)
14,350 per second.

TUNNEL, INLET, AND WHEEL-PIT SLOT

PLAN NUMBER III



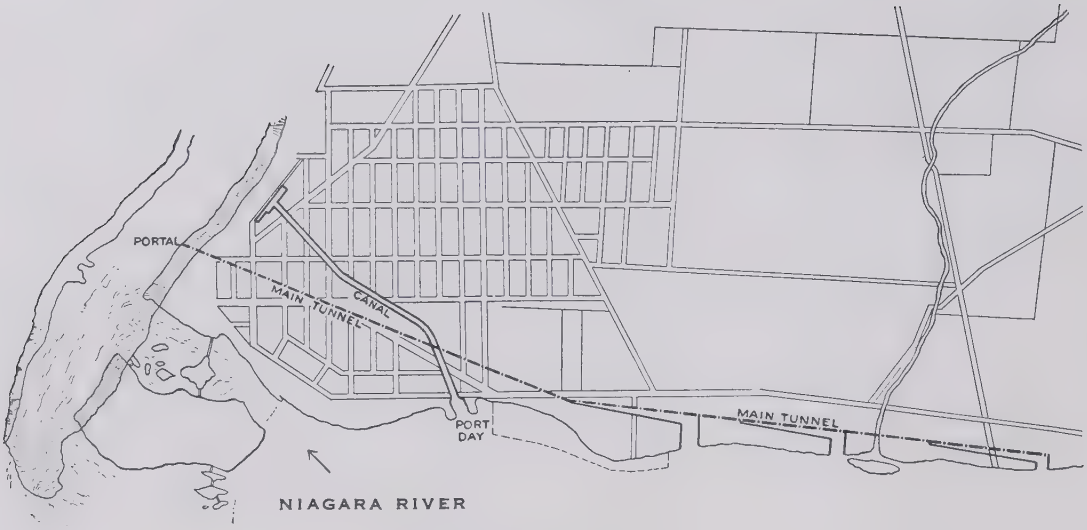
Transverse Tunnel Conduit or Inlet-canal and Main Tunnel
Cross-section Showing Wheel-pits and Cross Tunnels
Level Water at Port Day, 561 Feet Tide

Total fall 214 feet

The essential features of these suggestions included a circular tunnel of 24 feet diameter, 2½ miles in length, 1 mile westerly from the vicinity of Port Day to the lower river adjoining the abutment of Suspension Bridge, and 1½ miles easterly from Port Day, upstream on the river bank.

The plan also provided for twelve inlet-canals aggregating, with their connecting tunnels, about 3½ miles in length, all chiefly in rock excavation, each having an opening on the river with a right angled wharf parallel to the river and opening downstream to the west. These canals were designed to furnish water for a series of 238 factories each supplied with 500 horse-power from its corresponding wheel-pit with connecting discharge to the main tail-race tunnel, and comprising not less than 6 miles of rock excavation in addition to the vertical shafts.

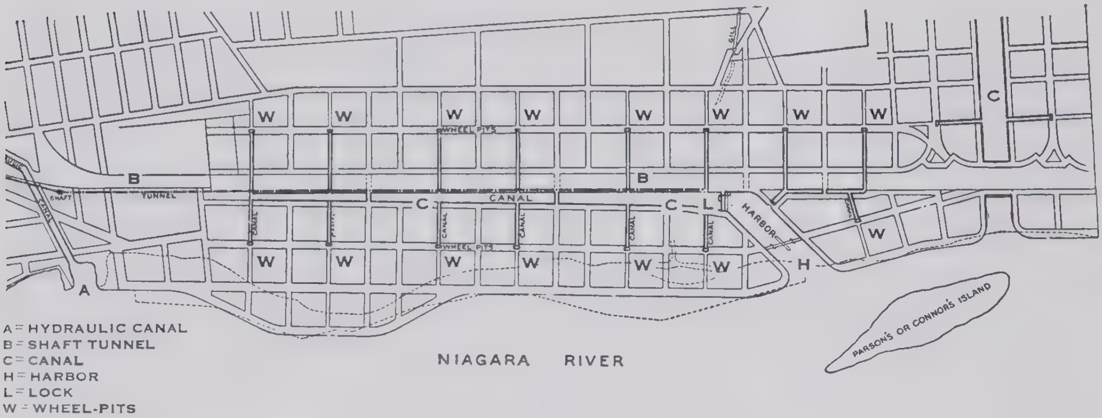
PLAN NUMBER IV



Three Inlet-canals

The twelve inlet-canals have been reduced to three and these have westerly extensions at right angles over and parallel to the tunnel beneath.

PLAN NUMBER V

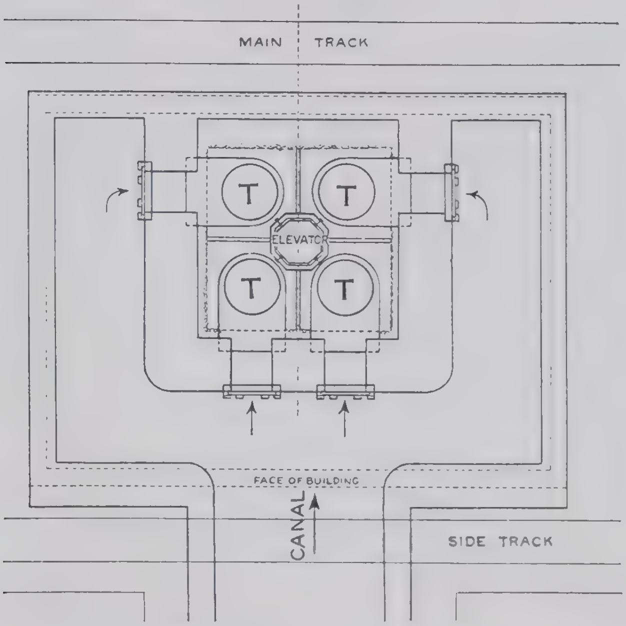


One Inlet-canal from Harbor

Plan showing development of the property to utilize 120,000 horse-power. Two inlets: one much wider than the other for use as a harbor, feeding a tapering canal with cross canals to the property on the northerly and southerly sides of the railroad tracks. Tunnel located under the main canal, with wheel-pits for the full development arranged with separate penstocks and inlet gates and with power-houses common to four mill lots of 12,200 horse-power each, the smaller inlet intended for wheel-pits south of the railroad. The location of four factories upon a group of four independent mill-sites and wheel-pits, is a noteworthy prototype.

TUNNEL, INLET, AND WHEEL-PIT SLOT

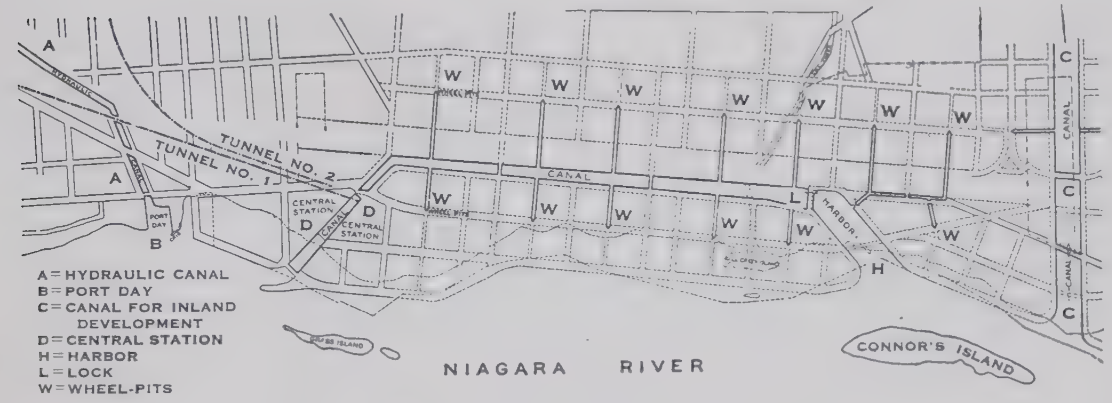
PLAN NUMBER VI



Four Turbine-shafts in One Wheel-pit

Plan showing head of lateral canal, wheel-pit, elevator and outlines of power-house common to four mill lots of 1200 horse-power each, with separate penstocks and inlet gates, also railroad tracks for mill service.

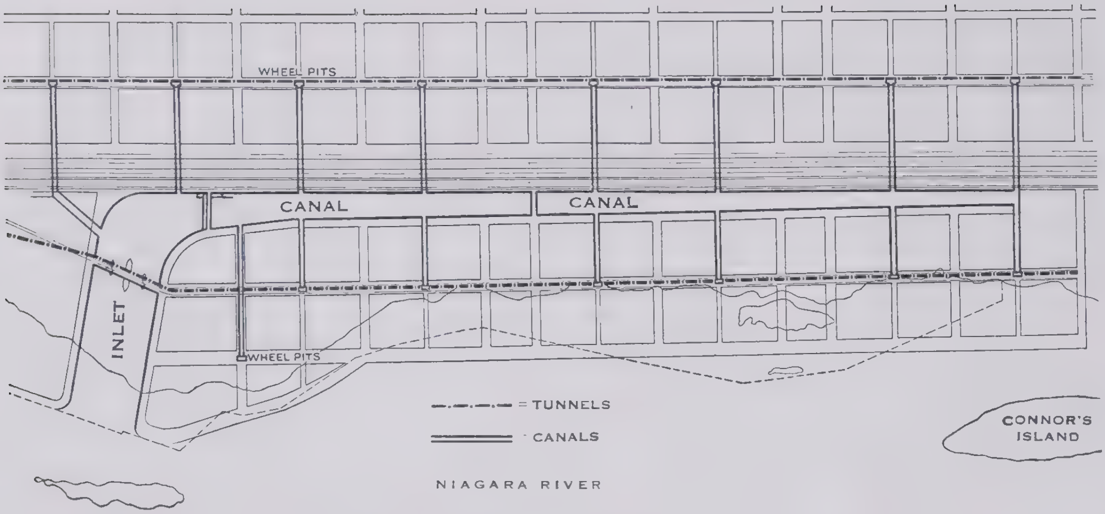
PLAN NUMBER VII



Main Tunnel Under Canal

March 21, 1891. Similar to previous plan, with modification by extending the inlet-canal back to the river as a loop so as to facilitate the flotation of ice downstream. Also providing for a second main tunnel, following a wide curve to a discharge lower down the river. Two central stations suggested.

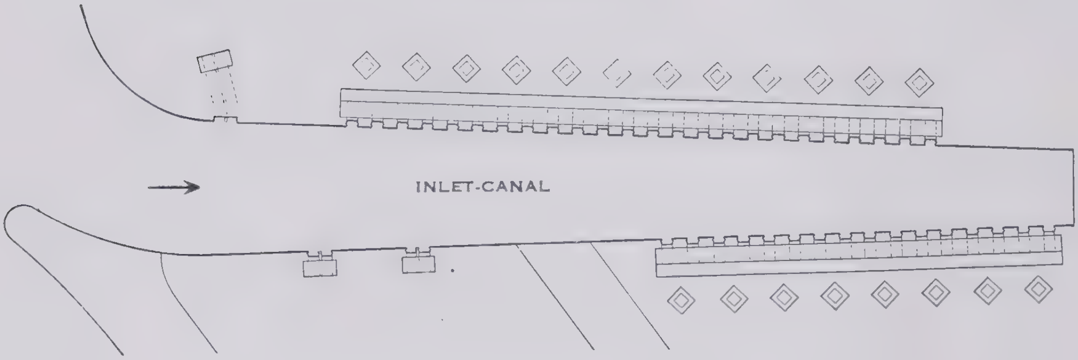
PLAN NUMBER VIII



Single Inlet with Lateral Canals

A single wide inlet with an upstream extension to the extreme end of the tunnel, the intension being to distribute the water to wheel-pits located to the right and left of the canal, with discharge tunnels, immediately below the canal leading into the main tunnel, and with an additional tunnel north of the railroad tracks carrying the water discharged from wheel-pits on the northerly side of the railroad tracks, into the main tunnel in the vicinity of Port Day. For full development of 120,000 horse-power.

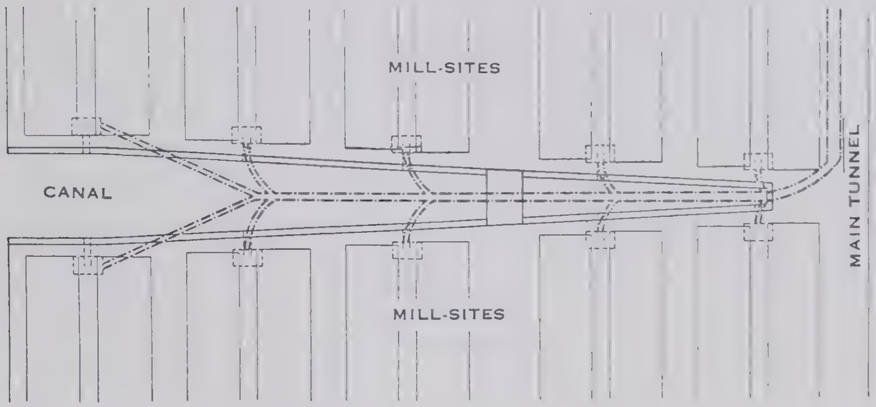
PLAN NUMBER IX



Single Inlet with Two Central Stations

July 8, 1891. Inlet-canal and head gates for two central stations with turbines arranged in groups of four, for the development of more than 100,000 horse-power.

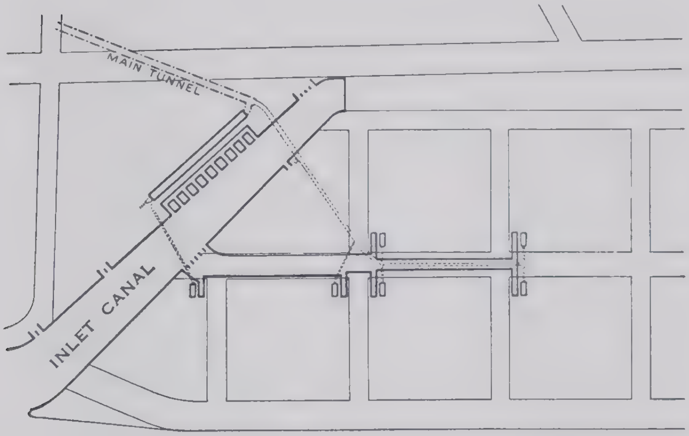
PLAN NUMBER X



Single Inlet for Individual Mills

Single inlet-canal 1075 feet long, 120 feet wide at the river entrance, tapering to 24 feet. Wheel-pits designed five on each side of the canal, for mill-sites, the discharged water passing through short tunnels connecting with a cross tunnel on the line of the canal leading by a curve to the main tunnel. For development of 20,000 horse-power.

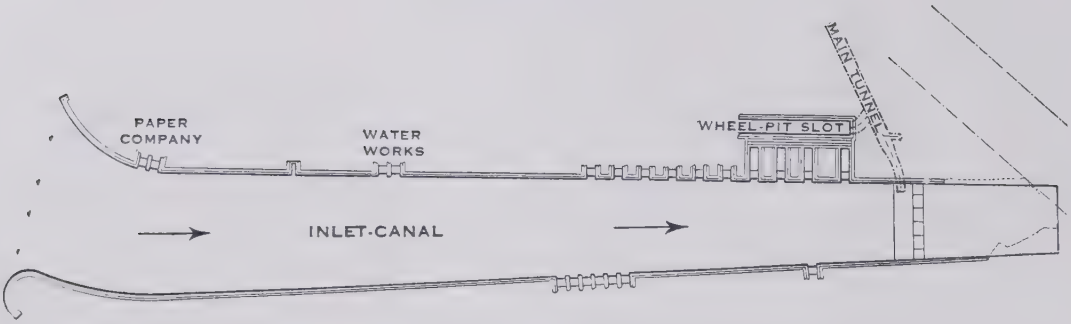
PLAN NUMBER XI



Single Inlet for Central Station and Individual Mills

June 17, 1892. Inlet-canal with power-house with location for turbines and canals for wheel-pits on mill-sites on the other side of the inlet-canal with discharge by small tunnels to a connection with the head of the main tunnel.

PLAN NUMBER XII



Single Inlet for Two Power-houses

June 13, 1893. Plan of canal as first constructed, intended for two power-houses of 50,000 horse-power each, one on each side of the canal with water-inlet gates for the lessees, the Niagara Falls Paper Company and the Niagara Water Works.

The first adoption of a pit or slot for all the turbines of a single power-house.

Some of the various plans shown above indicate successive changes made that finally resulted in the substitution of a single short inlet, of a central station for development and distribution and a tunnel smaller in size—21 feet by 18 feet 8 inches instead of 24 feet diameter, different in form, a horseshoe instead of a circle; shorter—6700 feet instead of 31,680 feet; and discharging, partly below instead of entirely above river water level, 14½ feet below instead of 5 feet above; a grade of 4 feet per 1000 feet instead of 10 feet per 1000 feet for 1½ miles and 20 feet per 1000 feet for 1 mile; and a head of 136 feet instead of 81 feet to 120 feet.

LOCATION OF TAIL-RACE TUNNEL

In the consideration of the final location of the main tail-race discharge tunnel there were several points already established. The lower portal, in order to be as near as possible to the falls, was located adjoining, on the north, the pier of the new Suspension Bridge, for which the necessary land had already been purchased.

At the upper end it was necessary for the tunnel to connect with the wheel-pit slot, and this was to be located near deep water where ample space would be available for the inlet-canal and the central power stations. Ample land had also been acquired for these purposes adjacent to Port Day on the upstream side.

As the hydraulic studies continued, the location of the upper portal of the tunnel was carried inland and nearer the lower portal, shortening the tunnel length and establishing its entire line without a curve.

In the spring of 1890, the length of the so-called first section of the tunnel, in fact, the entire length constructed, was tentatively considered at 7000 feet and later 7300 feet; in July it was considered as 8000 feet, and on July 31, it was finally, by elimination at the upper end, established at 6700 feet. Because the shore is much steeper, and the water deeper than higher up the river, and because it is nearer to the shortest tunnel, it was considered particularly suitable for the inlet-canal and its central power station. These changes in proposed length represent in part the uncertainties of the location of deep water areas that were being surveyed and critically examined from the point of view of currents, depths and ice floes.

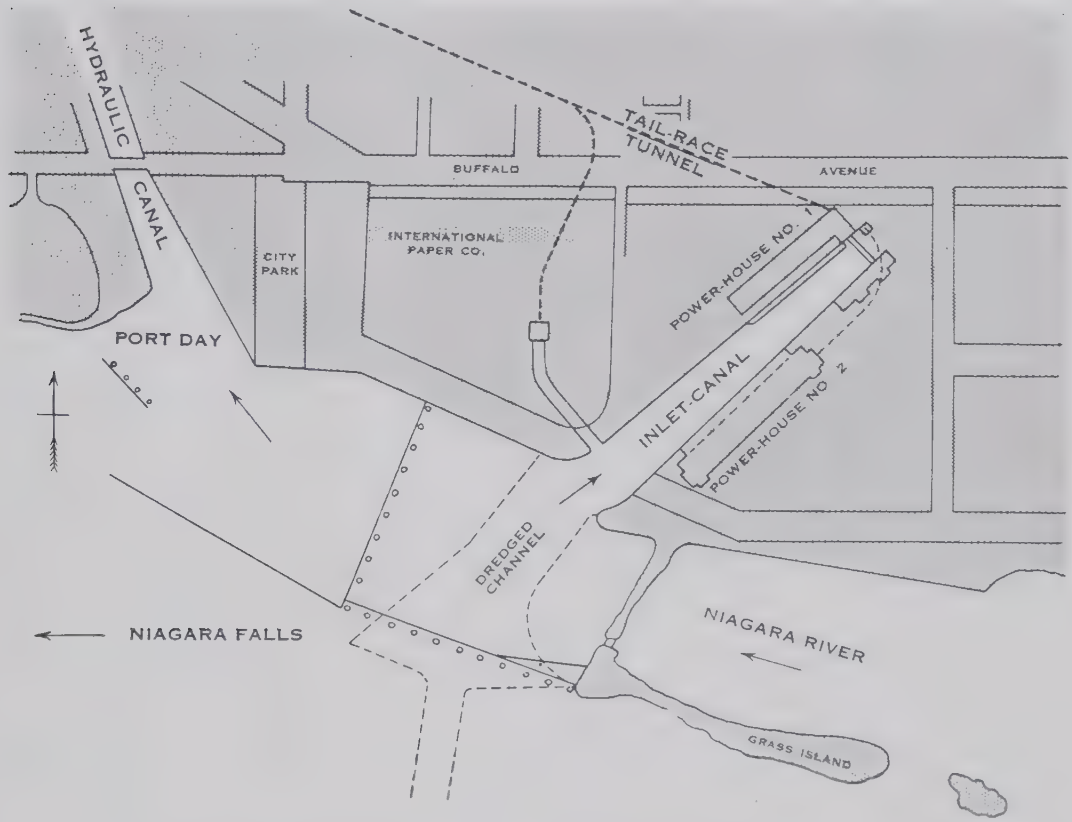
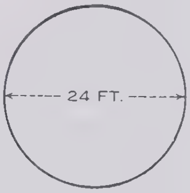


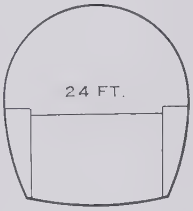
Diagram of Inlet-canal, Power-houses, and Tunnel

TUNNEL DIMENSIONS

In designing the main tunnel, Mr. Herschel adopted the tunnel capacity first proposed by Mr. Evershed to accommodate 238 mills of 500 horse-power each, and limited the capacity of the first tunnel to 120,000 horse-power (24-hour power) "as good a limit to set for the first tunnel as any other, as it leads to a fair sized tunnel to be constructed by successive steps; and is in itself, a large block of power. It is equal to 10 Holyokes, and to a dozen of Minneapolis; or to 20 Lowells, etc."

The tunnel section proposed by Mr. Evershed had a diameter of 24 feet and a sectional area of 484 square feet, and the partially rectangular section was designed by the chief engineer of the company to be equivalent in ultimate area to the 24-foot circular section suggested by Mr. Evershed.





Mr. Herschel first proposed a preliminary tunnel, as per sketch, of small capacity, that could be enlarged from time to time, according to the demand therefor, without interfering with its use.

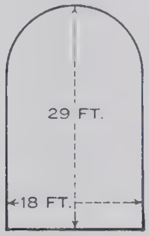
The two small benches cut into each side, just above the 20,000 horse-power water line, permitted the placing of a temporary working platform from which the final enlargement could be made. This program of construction anticipated the extension of the tunnel upstream, tapering in diameter from 24 feet for the first mile, to 16 feet for the second mile and 10 feet thereafter, for the cost of which the revenue from the first 20,000 horse-power would materially contribute. This scheme would have been and was frustrated by the necessity, subsequently developed, of lining the tunnel, as under that condition the first tunnel to be built would be that of the complete 120,000 horse-power or final capacity of the tunnel designed. The adoption of the central power station limited the tunnel in length to that necessary to reach the power-house. Any power requirements beyond the 120,000 horse-power capacity were dependent upon the second tunnel for which the right-of-way had been secured in 1889 pursuant to the recommendation of Mr. Herschel, and as indicated on Plan Number IV.

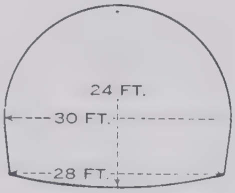
The shape of the tunnel first proposed by the board of engineers was as a canal partially rectangular, 18 feet wide, of upright walls and an arched top 29 feet above the floor, with a sectional area of 490 square feet.

Before the sinking of the shafts and the commencement of tunnel excavation, while confidence obtained in the stability of the strata considered probable for the tunnel excavation, the following design, being that commonly used at that time for double-track railroad tunnels, was under consideration by the board of engineers.

After the issue of invitations for the submission of competitive projects to the International Niagara Commission in January, 1891, a modification of the tunnel cross-section, as here indicated, was suggested, thereby increasing the sectional area, and starting the horseshoe form that was finally adopted.

The advantage gained in horse-power, per cost of tunnel construction, was appreciable.



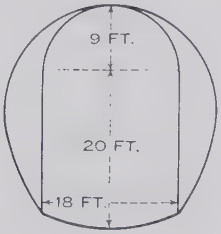


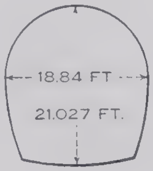
This form was approved at the tunnel conference in London in September, 1890, when the following dimensions were adopted.

LINING OF THE TUNNEL

The desirable limit of roughness of the interior of the tunnel, in rock unlined, or "tolerably smooth" as Mr. Evershed recommended to reduce friction to the minimum economically possible, was described as follows:

> Square projections must be beveled off, and regard must be continually had to the intended use of the tunnel as a waterway. Any face toward the current of the water forming an angle of thirty degrees or more with the axis of the tunnel, shall be considered an abrupt face prohibited.





The necessity of this provision against roughness was obviated by the later decision to line the tunnel with a smooth and practically indestructible lining, 16 inches thick, of hard-burned Buffalo brick, set in Portland cement.

The tunnel as originally projected by Thomas Evershed in the year 1886 was not intended to be lined; his plans and estimates making no provision therefor were approved on July 19, 1886, by State Engineer and Surveyor Elnathan Sweet; on May 31, 1887, by Jabez Church, past-president of the Society of Engineers of England, and on June 17, 1887, by G. N. Abernethy, member of the Institution of Civil Engineers (England).

The consideration of this matter included the possible necessity, in the interest of safety and stability in operation, of lining some part or all of the tunnel, notwithstanding the great expense involved.

Advice was sought in many directions likely to afford the guidance of experience as well as of scientific forethought.

Since the dip of the rock strata inclined against the grade of the tunnel, which would probably pass from the Niagara hard limestone into the Rochester argillaceous shale for its major length, as will be seen by the profile of the rock stratification shown on page 49, it was recognized that the situation required very careful study.

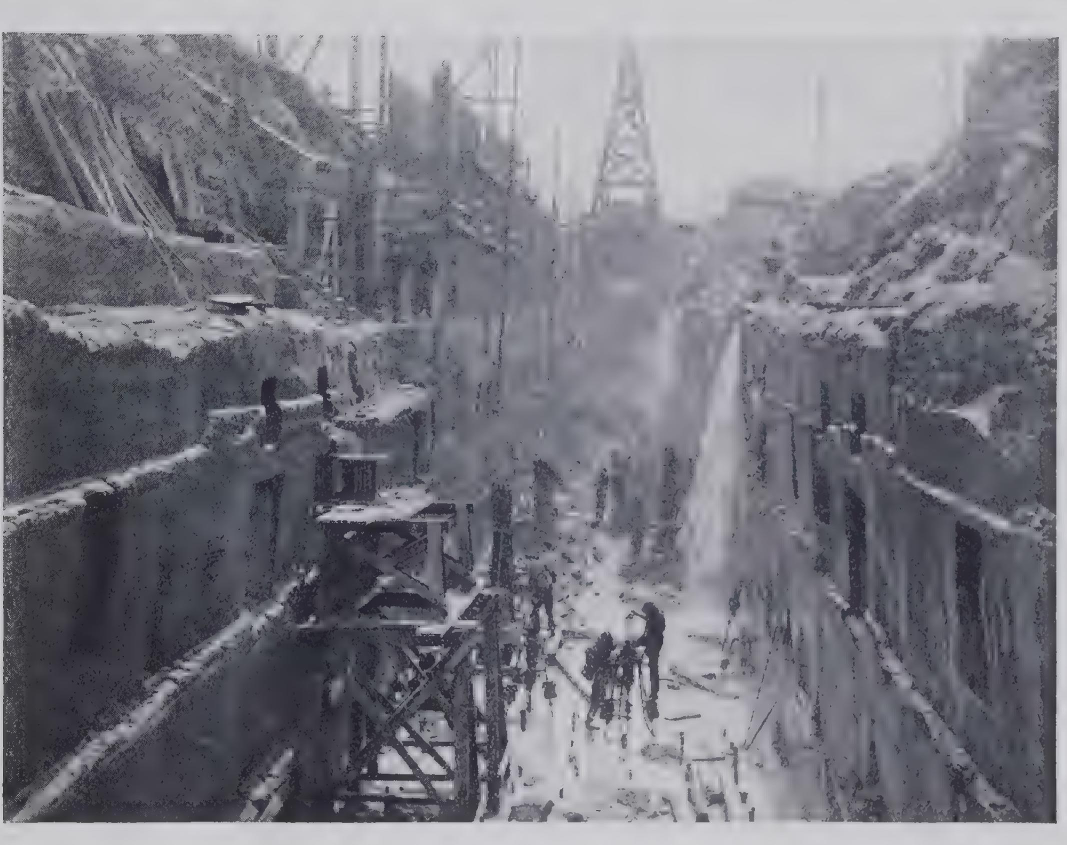
The Niagara limestone is probably one of the best building stones on the company's property. The shale is less desirable than the limestone because it does not break into good shapes for building uses and its crushing strength per square foot is 78.32 in proportion to 100. of the limestone.

Much investigation locally was made of the various wells, wheel-pits, railway cuts and river banks, where the shale had been exposed to weather conditions for greater or less periods. It was found that the exposed surfaces had crumbled from the effect of moisture and frost, but not enough to disturb the members of the board of engineers who were unanimous, long before much progress had been made in the excavation of the tunnel, in the conclusions as stated by the chief engineer "that lining is unnecessary for stability, safety and economical operation," and of the hydraulic engineer whose conclusions were "distinctly against the construction of a tunnel lining. Considerations of attainable economy in the design and construction of the whole work decide against it." Several foreign engineers, who had *not* visited Niagara, advised, in studying the plans for utilizing the water-power, that the tunnel should be lined.

Dr. Julius Pohlman, of Buffalo, a specialist in the geology of the Niagara basin, advised in October, 1890, that the tunnel be lined, and in his public lectures in Buffalo called attention to the characteristic of the shale, that upon exposure to the atmosphere would expand and lose its cohesive stability.

Again the quantity element arose in the unprecedentedly large surfaces under pressure, in the roof of the great tunnel, freshly exposed to the atmosphere, that became the subject of solicitude. Several test holes were drilled down to the lower lines of the possible tunnel, before commencing work, to ascertain the local conditions of the several strata. The cores of rock were submitted to laboratory tests and were pronounced satisfactory by scientific experts, so far as that limited field of observation could permit.

In the sinking of the portal shaft a broken seam of shale was encountered unexpectedly, that caused renewed scrutiny of the tunnel roof, then subjected to driving with and without explosives. The three shafts had been sunk to the tunnel level and the headings driven for 50 to 75 feet from the shafts. The character of the shale was fully shown in this and all other work in the material in the several headings and at the portal, where it quickly crumbled upon exposure to the air, and necessitated timbering to avoid serious falls from the roof. Notwithstanding speedy action to avoid danger by timbering, the unexpected happened from time to time, and several accidents, with serious injuries and fatalities occurred, while preparations were being made to line the



WHEEL-PIT NUMBER TWO UNDER CONSTRUCTION
View from below, looking south

entire tunnel to assure present safety during its construction and confidence in the continuity of its service when in operation.

Two specimens of the cores were examined in London under the direction of Professor Unwin. It appeared that the greater part of the shale was made of carbonate of lime in small crystals, closely bound by cement that was shown in the microscopic examination and seemed to justify the classification of the so-called shale as argillaceous limestone.

It was also seen that the stone was much more fissile in the direction of the horizontal strata than expected; a tendency to cleavage that was recognized from the slab-like pieces that fell from the roof of the tunnel in its excavation.

By very careful instrumental determination of the width of the tunnel excavation at this time, the chief engineer of construction then in charge of that work, ascertained that the width of the excavation between the two opposite sides decreased measurably in twelve consecutive hours. This characteristic was met subsequently in the operation of the wheel-pit as will be explained in the reference to that feature of the hydraulic system.

There was much water encountered in sinking two of the tunnel shafts, particularly in Power-house Number Two, where four streams spouted from crevices in different strata of the rocks and required special confinement to avoid hindrance in the work.

The most important change in the contract of October 4, 1890, for the construction of the tunnel, was made in June, 1891, when it was determined to line the entire tunnel system with hard-burned brick, laid in Portland cement, in four courses. A supplemental agreement for this work was made with the contractors as provided in the original contract, should changes of design be desired.

The decision to line the tunnel, as well as all other important excavations in the shale, resulted in an increase in the cost of tunnel of $416,000. This important increase in the estimated cost of the works, not anticipated by the company nor its engineers, was promptly assumed, not only to give safety to those engaged in the construction, but in order to assure uninterrupted use of the tunnel, confidence in its stability, and the minimum expense in its maintenance.

SLOPE AND VELOCITY OF DISCHARGE

The slope of the tunnel and the velocity of its discharge were much discussed by the engineers, particularly on account of the unprecedented quantity of water and the size of the cross-sectional area of the tunnel proposed.

The Evershed plan provided for a main tunnel with an area equivalent to a tolerably smooth tunnel of circular form, 24 feet in diameter. "Its mouth," he declared, "shall be located as low as high water below the falls will permit. It shall have a descent, from a point half mile above Port Day to its mouth, of one in one hundred, or 52.8 feet per mile."

"If the amount of water which will pass through a tunnel of 24 feet in diameter, having a descent of one in one hundred, is used economically under heads ranging from 124 feet to 79 feet through turbine wheels of the latest patterns, it will give a result equal to 119,000 horse-power; or in other words is equal to 238 factories of 500 horse-power each."

The first considerations of the hydraulic problem were based upon these statements by Engineer Evershed.

An English hydraulic engineer, of experience and high professional position, who had been invited to submit to the International Niagara Commission a project of hydraulic development at Niagara, wrote in anticipation of his project, that

> The fall and dimensions of the tail-race tunnel bear so importantly upon the design of the hydraulic motors, that I shall be glad to be permitted to suggest that some precautions may be found necessary to prevent undue change of head in the tunnel beneath the motors.
>
> I suppose none of us have experience of a tunnel working under similar conditions on so large a scale; but judging from the behaviour of long culverts running nearly full and discharging at high velocities above water, I have some fear that there will be such periodic oscillation in the discharge as may permit air to travel up the tunnel a long distance at one time, and be suddenly discharged at another, and if this happens there may be considerable oscillation of the water level at the head of the tunnel as well as considerable retardation of the average flow. Assume the tunnel to be running full near the upper end, it certainly will not run full near the lower end, unless some special arrangement is made by a huge downpipe or otherwise for the outlet end to be constantly under water.

Another engineer declared

> that there would be great instability in the flow through the tunnel, unless the water fills it up to the roof or very nearly so, in every part. Water flowing in a rectangular channel, a little deeper than 24 feet would certainly have gigantic standing waves if its velocity is 28 feet per second.

Other foreign hydraulic engineers favored a tunnel that from first to last would be under water or that could be made to run full bore with only part of its total required discharge capacity.

Submergence, some believed, should be only what will enable the condition of full bore discharge to be obtained when required, by a gate raised from the bottom, but so arranged as to be removed as an obstruction when it is not needed.

Mr. Herschel's comment upon these expressions of fear and doubt was, "it is very questionable to my mind (and my mind is the result of handling water, and dealing with it as it acts and moves day after day, and for 25 years and over added to whatever learning I may have acquired) whether any wave proper be possible in a current running so much as 28 feet per second. So that instead of fearing waves, on account of that velocity, I look upon that velocity as a safeguard against waves; and tending against oscillation as well."

RESULTS OF TUNNEL CONFERENCE

At the tunnel conferences in London, October, 1890, these and all points of view cognate to the great tunnel were carefully considered and after several days of sessions devoted to the subject, the following dimensions were unanimously adopted and the results therefrom understood as those considered best for the enterprise.

Tunnel	Length from portal to inlet discharge connection, both points then located,	6700 feet
Grade	4 feet in 1000 feet, difference of level at ends	26.8 feet
	Grade at portal changed into an ogee commencing at a point 90 feet from the portal and dropping in that distance nearly below the average low water of the river, thus permitting fully one half of the tunnel flow to discharge below the surface.	11 feet
Portal	Top of tunnel arch 9 feet above mean water level, equivalent to bottom of tunnel 20 feet below mean water level, or 11 feet below the average low water of the river.	
Cross-section of Tunnel	Horseshoe section throughout this main tunnel as per design on page 28.	
Velocity per second		26.5 feet
Discharge per second	Slightly increased at the portal by the 11-foot ogee of the last 90 feet of the grade	8900 cubic feet per second
	Horse-power, estimated capacity, full bore	120,000 horse-power

The tunnel has been used to the limit of its capacity on a great many occasions, the maximum power obtained from the originally installed machinery being about 107,000 horse-power in the two power-houses on the inlet-canal. The ogee part at the river end probably never was full, the water in that 90 feet always running much more swiftly than upstream from the ogee.

Without the ogee, and extending the tunnel section without change to the face of the portal, the "back-wash" from such a large quantity of water would almost certainly have undermined the portal masonry. It was as a preventive of such a catastrophe, Mr. Herschel explains, that the ogee was designed.

It was understood that some adjustable regulator might be required at or near the mouth of the tunnel. This was provided, in the granite facing of the portal, by a cast-iron groove bolted to it, also to be used for stop planks to keep out the water of the river should it become desirable at any time, for inspection. The stop-plank barrier has never been used.

Water levels of the river above and below the falls, at the portal of the tunnel and at the entrance of the inlet-canal, differ 217 feet, being the total fall available, which is utilized as follows:

Utilized by the turbines	140 feet
Head lost in the tunnel	49 feet
Head lost in paper company's tributary tunnel	11 feet
Remainder, possible useful reserve	17 feet
TOTAL	217 feet

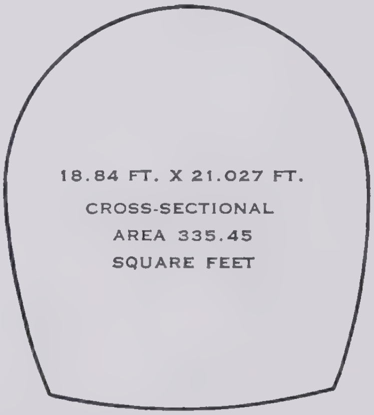
The construction of the main tunnel and the inlet-canal was carried out under the terms of a contract awarded in competition, September 12, 1890. Work commenced October 4, 1890, and was finished December 20, 1892, having occupied two and one-quarter years.

It was directed by George B. Burbank, member of the American Society of Civil Engineers, as resident consulting engineer, assisted particularly by Albert H. Porter, resident engineer, William S. Humbert, division engineer, and J. C. Tait and George F. Simpson, assistant engineers, the latter having made all designs and details for the construction.

TECHNICAL DETAILS OF CONSTRUCTION

The technical details used in the subsequent portion of this chapter were chiefly prepared, upon the completion of construction, by Mr. Simpson, who, as an expert in stereotomy, was in charge of the tunnel intersections, important though minor parts of tunnel design and construction.

The tunnel was driven by using a top heading and two benches, from the lower portal and from two shafts located 2540 and 5090 feet respectively from the lower portal. The general plan of excavation was to carry forward the five headings from the two shafts and the lower portal. The upper bench followed within about 50 feet of the heading and the lower bench was excavated a short distance, less than 100 feet, ahead of the tunnel lining. The best progress in driving a heading was 94 feet in one week. The record in five headings, including upper benches, was 331 feet in one week or an average of 66 feet at each heading.



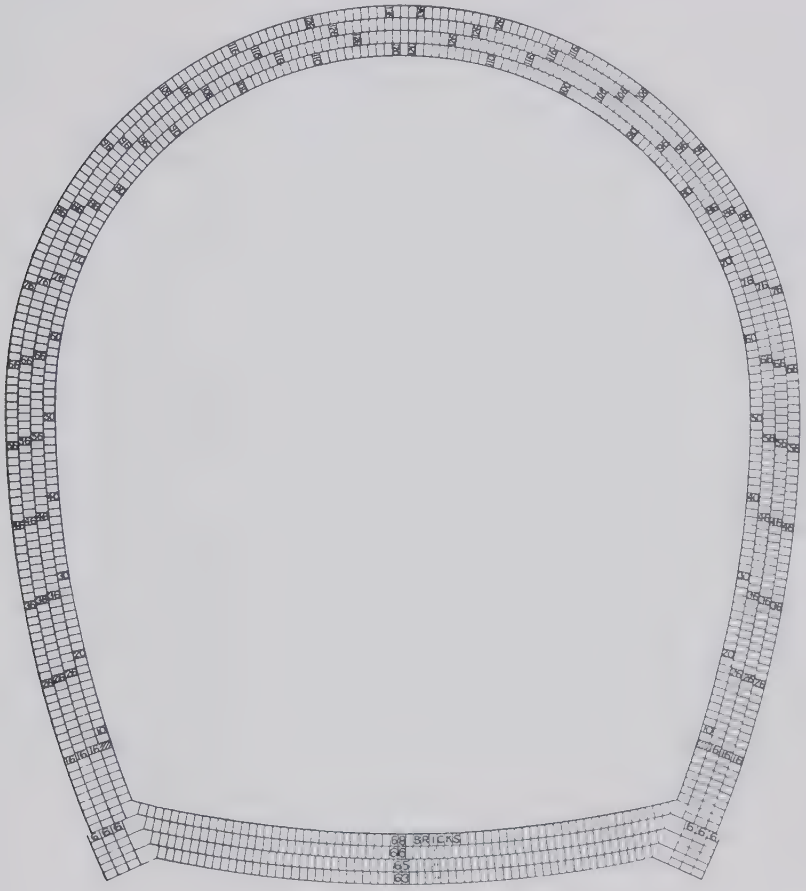
Cross-sectional Diagram of Tunnel

The Main Discharge Tunnel has a slope from Wheel-pit Number One of 0.004 for a distance of about 1700 feet and 0.007 for about 5100 feet to a point about 90 feet from the lower portal. It drops 11 feet in the last 90 feet of length so that fully one-half of the discharge takes place below the average low water of the river. Excepting for the last 90 feet, the tunnel is above the level of the river and will drain itself quickly after the water is shut off from the turbines.

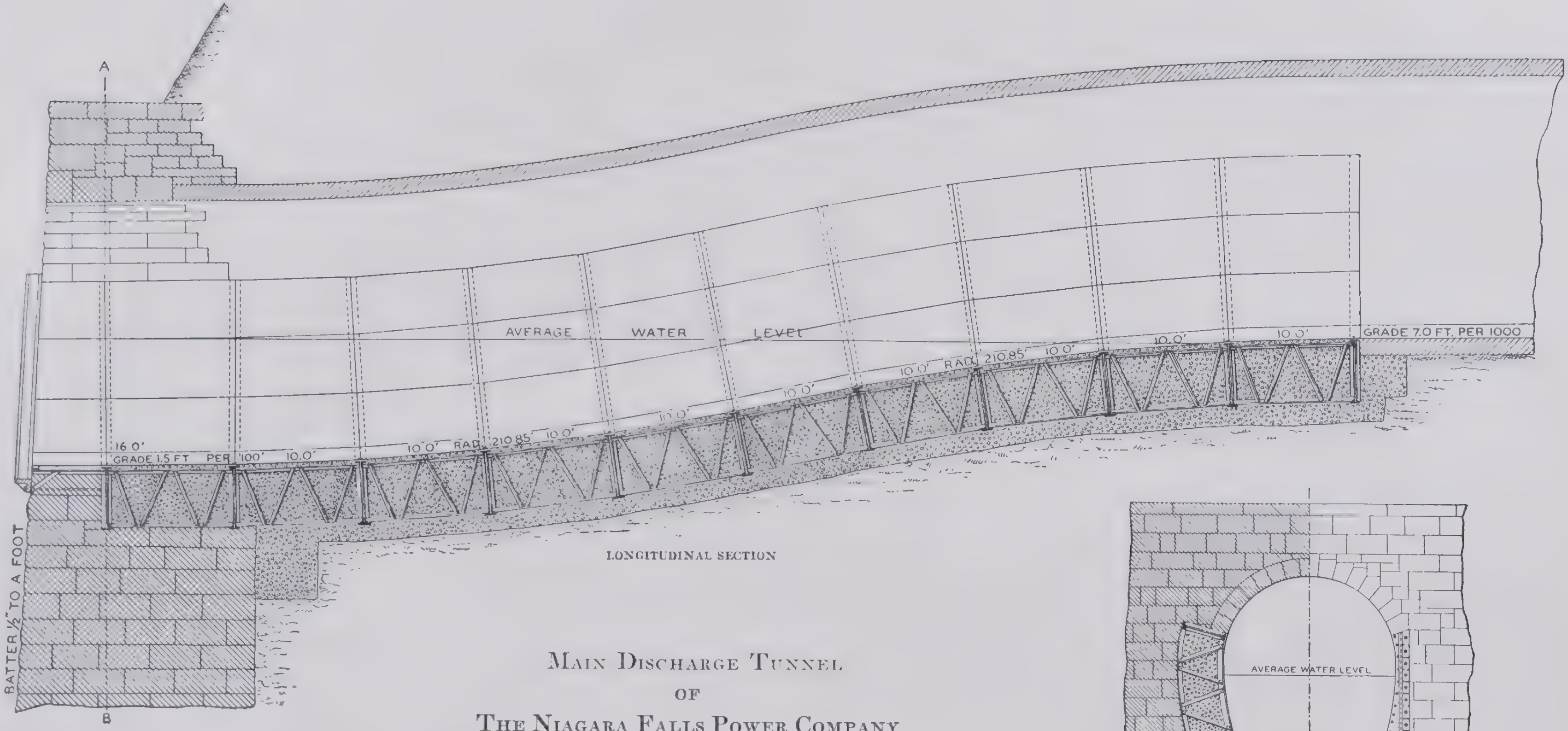
The Cross-section is in shape like a horseshoe with toe part upward. The bottom, sides, and top are all circular curves. The inside radius of the bottom is 29.6 feet, of the side walls 29 feet, and of the top 9.42 feet. At the top of the invert, or bottom of the tunnel, it is 14.77 feet wide and the versine of the bottom is 0.936 foot. The side walls are 10.671 feet high and their tops are 18.84 feet apart. The top is a semi-circular arch. The extreme dimensions inside the lining are 21.027 feet in height and 18.84 feet in width, with a cross-sectional area of 335.45 square feet.

Nearly the whole length of the tunnel a heavy timber arch was placed every 4½ feet. These arches were covered with poling boards and the space above packed full of stone. As the brick lining was placed, the space outside the side walls and up to about 45 degrees above the spring line of the arch was filled with stone laid in cement mortar. Above this the filling was with stone without mortar.

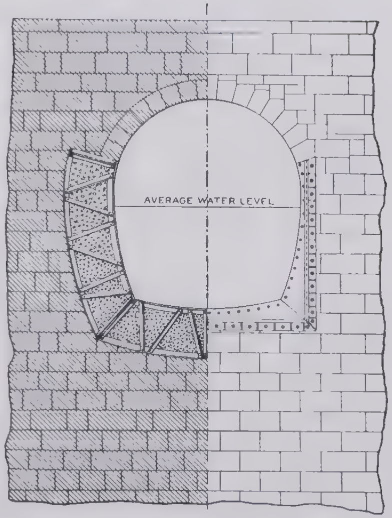
The main tunnel is brick-lined from the portal at the lower river to the extension and to a connection with the wheel-pit, a distance of 6950 feet. The last 20 feet of the extension is a reduction of the horseshoe tunnel to one of about ¾ the area of cross-section. The tunnel was excavated a short distance beyond the reduction, whence it was extended in 1902 as the tail-race of Power-house Number Two, a total distance of 7438 feet from the lower portal. The brick lining of the tunnel is of four rings laid in "rowlock" courses and is 16 or more inches thick. The lining course of the invert is of vitrified paving brick, and all the bricks used are hard-burned. The bricks are all laid



Brick Lining of Tunnel (Cross-section)



LONGITUDINAL SECTION



LONGITUDINAL SECTION A-B ELEVATION

MAIN DISCHARGE TUNNEL

OF

THE NIAGARA FALLS POWER COMPANY

below the cliff, at the edge of the river, showing

(1) *partial submergence of tunnel mouth*
(2) *reverse or ogee curve of portal section*
(3) *average water level in portal section of tunnel, when not discharging tail-race waters from turbines*
(4) *masonry and reinforced concrete*

in "stretcher" courses except the special brick at the bottom of the side walls and one course of "headers" eight courses above the top of the invert in the two inside rings of the side walls. This header course is designed, should it ever become necessary to reline the invert and bottom of the side walls, to enable the inside rings of the side walls to be removed below this course without disturbing any of the bricks above it. In building the brick lining the side walls were built first, then the arch, and finally the invert. The first four bricks of the inside ring of the side walls are special brick and each extends into a course in the invert, thus filling up the triangular space that would be between the invert courses and the side walls, where only the usual shaped bricks were used.

Tunnel Discharge in Lower River Adjoining Suspension Bridge

Portland cement was used exclusively instead of American[1] cement for mortar in laying brick and stone masonry in the tunnel and wheel-pit, involving an increase in cement costs of about $20,000. This was considered a small premium to pay for such an assurance of stability in masonry construction, under the special conditions prevailing.

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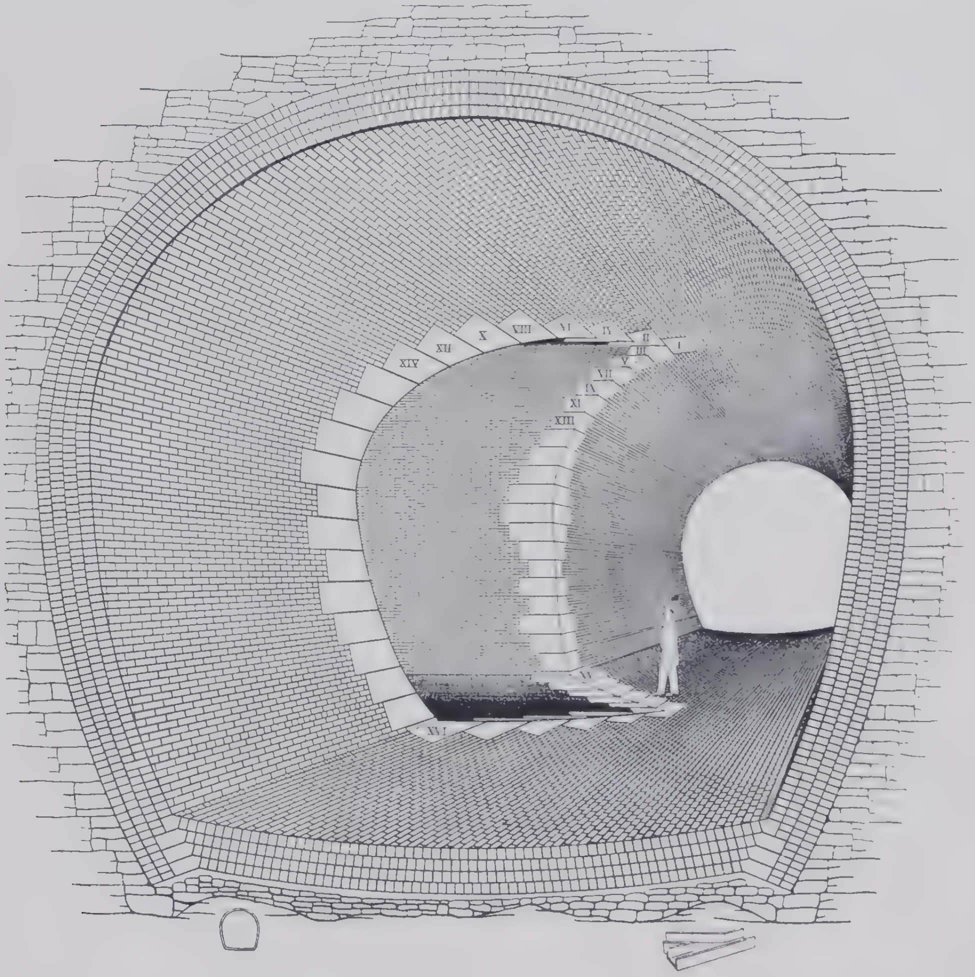
[1] So-called "American" or "natural" cement was then largely used. Only a small quantity of Portland cement was then made in America, most of that used being imported from Europe.

The portal consists of stone and concrete extending solidly 38 feet below the surface of the river to a bed-rock ledge of gray medina sandstone that was considered entirely satisfactory as a foundation.

The portal masonry extends 27 feet below the bottom of the invert, 11 feet below the water, 18 feet from the face of the masonry, along the tunnel, and 42 feet across it. In this are imbedded five heavy longitudinal steel girders joined together by transversal girders at every 10 feet on the curve of the bottom. One of the longitudinal girders is at the bottom of the invert and extends 95.2 feet from the face of the stone masonry measured on a horizontal line or 96.08 feet measured on the reverse-curved, or ogee, bottom of the tunnel. This girder is so shaped that for the first 6.08 feet it is level, for the next 50 feet it forms a curve concave upward, and for the remaining 40 feet of its length it forms a curve convex upward. The other longitudinal girders are of nearly the same length and one is placed at the bottom of each side wall and one a little above the top of each of them. These girders are covered on the inside with steel plates which form the inside of the tunnel to 12½ feet above the top of the invert, of the same shape in cross-section as elsewhere. The axis of the tunnel like the bottom of the invert is a reversed curve in the vertical plane. Behind these plates the spaces between girders are filled with concrete; thus the first 95 feet of the tunnel is so bound together that no part can be torn off without all going with it, and its size and weight will prevent that happening. The curved shape of the profile is designed in part to discharge the water of the tunnel below the surface of the lower river and so form a water cushion for it to strike against.

The facing of the portal is of granite with a cast-iron groove bolted to it for stop-planks to keep out the water of the river if desirable at any time. These bolts extend into the masonry behind the facing. The granite used at the portal and at the bottom and top of the shafts and the intersections of the tunnels from the wheel-pits with the main tunnels was furnished by Brandywine Granite Company, of Wilmington, Delaware. That at the portal was cut at the quarry, except the keystone which was cut at Niagara Falls after the remainder had been placed.

At 2540 feet from the portal is shaft No. 1 and at 5090 feet from the portal is shaft No. 2. After the tunnel was completed at these points the shafts were reduced to a circular opening 5 feet in diameter, the center of which is 3½ feet from the center line of the top of the tunnel. At the top of the shafts a brick relieving arch 20 inches thick was thrown across them. Directly over the 5-foot ring at the bottom of the shaft and in the top of the relieving arch another circular opening of the same size was left. The six granite stones forming each of these rings were drawn to scale at Niagara Falls and cut at the quarry near Wilmington, Delaware.



Curved Tunnel from Wheel-pit to the Main Tunnel
(Note Voussoir Numbers[1])

At station 60+46 of the tunnel (60+46 feet from the portal) is the intersection of the circular tunnel from the wheel-pit of the Niagara Falls Paper Company. This tunnel is 7 feet in diameter and lined with brick masonry except at the intersection, which is of granite, the stones for which were dimensioned by graphic methods by Assistant Engineer Simpson.

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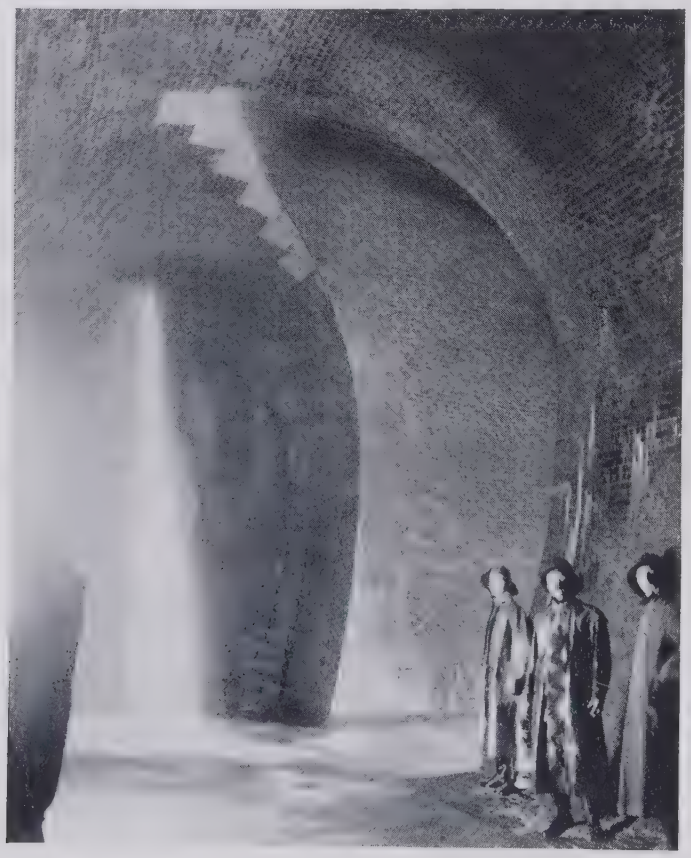
[1] See Volume I, page 250.

Between station 69+30 and station 69+50 the area inside the brick lining of the tunnel is reduced to three-fourths of the area to this point, but the horseshoe shape is retained and the same grade for the bottom of the invert. In doing this the lines at the top of the invert, at the springing of the arch, and at the crown of the arch converge to the corresponding points of the reduced tunnel. The intermediate points on the larger section are connected to corresponding points on the smaller section by straight lines.



View of Intersection of Wheel-pit Number One with Main Horseshoe Tunnel

At station 68+73.51 is the intersection of the axes of the main tunnel and a curved tunnel of the same size and shape from the company's wheel-pit slot. The intersection of these tunnels is a novel piece of work. This part of the tunnels, as all other parts of this system of tunnels, is designed to carry water under a small pressure and therefore must resist an outward, as well as an inward pressure. Until the tunnel is working constantly to its full capacity the outward pressure will vary from time to time, and hence the resultant pressure on the linings will not be constant.

The main tunnel at the point opposite the intersection of the discharge tunnel from the wheel-pit was constructed as follows: hard Shawmut vitrified clay brick was used for about a distance of 50 feet, up to the springing line; above the springing line the hard selected Buffalo brick was used. The timbers were of Georgia pine, 4-foot centers, with 3-inch lagging. For a distance of 8½ feet above the springing line the backing consisted of rubble masonry mixed with mortar of one to two American natural cement. All of the backing was laid carefully by hand, and there should be no fear of this backing or brick lining failing, as the work was constructed with the idea that there would be considerable hydraulic pressure at this point.

The intersecting tunnel is larger than is usual and is horseshoe-shaped of the same dimensions as the main tunnel, being 18.84 feet wide and 21.027 feet high inside. Its perimeter is formed by four circular curves, which make, at the intersection of the soffit surfaces, six quoins, each a part of a different ellipse, since the elements of the surfaces as well as the axis intersect the corresponding elements and axis of the main tunnel at an angle of sixty degrees.

Having fixed the width in the soffit for each stone generally, this fixed the number of stones in each quoin and the necessary changes for the peculiar special stones. There being no two stones alike in the whole intersection, all were special stones,[1] although a number in each quoin were similar in many details.

MAIN TUNNEL INTERSECTION WITH TEN-FOOT CIRCULAR DISCHARGE TUNNEL

The circular tunnel of 10 feet diameter intersecting the main tunnel of horseshoe section at station 69+14 was begun as an outlet for future wheel-pits on the north side of Buffalo Avenue. This enters at the level of the top of the invert and its extradosal surface extends from below the invert to above the side wall of the main tunnel. The arches at the intersection of the tunnel from the company's wheel-pit with the main tunnel will probably most impress the observer, but the engineer will recognize in the smaller intersection one of the most difficult problems in stereotomy. There are but few possible problems more difficult, and probably none so difficult has ever been erected by cutting the several stones at one place from drawings and constructing the finished work at another place.

The 10-foot tunnel, in common with the side tunnels, intersects the main tunnel at an angle of 60 degrees on a horizontal plane, and its axis is 5 feet above the top of the invert of the main tunnel. To obtain the proper direction for the joints, to resist the load that comes on the stones, a skew arch was used. It will be seen that the bottom half would be a left-handed skew and the top half would be right-handed and of an equal amount of skew. In an ordinary skew arch the face is a vertical plane but in this one the face is formed by part of a horizontal cylinder, the axis of which is 5 feet 8 inches above the axis of the intersecting tunnel.

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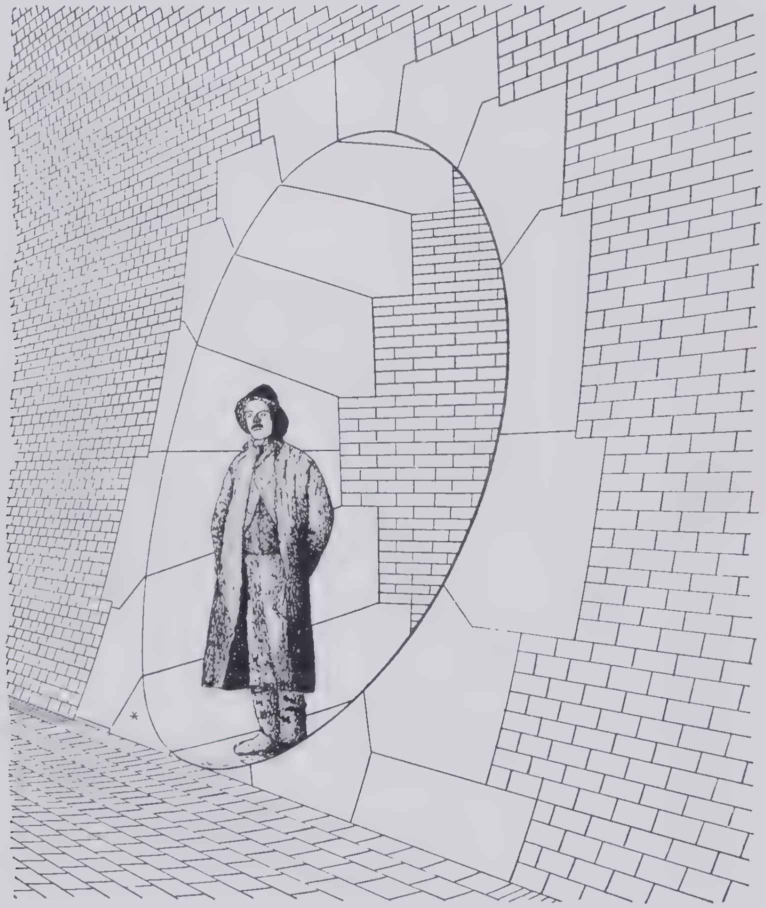
[1] See Volume I, pages 250–266.



Perspective Showing Intersection of Circular and Horseshoe Tunnels

In selecting the kind of skew arch to employ it was decided to use the helicoidal, although one of its chief advantages, that of all voussoirs being alike except the face ones, would be lost, as only face voussoirs were wanted in this arch. After deciding upon the number of brick courses in the lining of the 10-foot tunnel, the size of the stone was adopted so that 16 would make the circuit of the soffit, thus making nine brick courses to bond on the end of each stone. To do this in a proper manner the rear end of the stones must be cut by a plane at right angles with the axis of the smaller tunnel and the side of any stone, which reaches into the 10-foot tunnel beyond the next stone to it, must be cut by a plane in the axis of the 10-foot tunnel to form a radial bed for the brick courses lining the tunnel. As the rear ends of the coursing joints all end in the same heading joints spiral, the end of each stone in the arch is cut as above. While this bond of the brick on the stones at the end inside the small tunnel was one of the points to be thought of and provided for, it was about the last one to care for in the working plans and in cutting. The intersection of the soffits of the two tunnels claimed the first attention. This was drawn as a problem in descriptive geometry.

The engineer visited the quarry and directed the cutting of the first stone. The remaining stones were cut without any further assistance except such as could be given by mail. A similar but larger arch would be easier to cut as the difference between successive stones would not be so great, and the size and shape of one stone would be a partial guide in selecting a rough stone from which to cut the next one.

As there are no straight arrises in the coursing joints, the stones were set by using the three co-ordinates to the several points of each stone. No difficulty was found in doing this with the aid of the engineers, although an unusual method for a stone-setter. In setting these stones each one fitted its intended position in a manner highly satisfactory to all concerned, and the finished work is much more exactly as intended than is often obtained in the best straight work. As shown by measurements made since the centers and staging were removed, no point in the top half is more than ⅛ inch from the intended height above the corresponding point in the bottom half and none more than 3/16 inch from a plumb line through the corresponding point.

WATER-INLET OR CANAL

The inlet-canal extends 1400 feet inward from the river and is 100½ feet wide at the inner end. The side walls are straight lines to 175 feet from the river where the canal is 138¼ feet wide. At about this point, both sides turn downstream with a curve so that water entering the canal from the river reverses its flow. This is to prevent the ice being jammed into the mouth of the canal. As an additional protection from ice, three triangular steel piers are anchored to the bottom of the canal in a line across its mouth, and a wide sawed timber boom floats in front of the piers and ends of the walls of the canal. The bottom of the canal is excavated for much of its length in solid rock, the remainder being in the heavy clay of the river bed. The side walls are 17 feet high and 7 feet thick at the bottom and slope to 3 feet thick at 12 feet from the bottom, the top 5 feet being about 3 feet thick. The batter on the water side is 1 inch in 1 foot from the bottom to the top. The stone used is a very hard curly stone quarried at Buffalo.

The connections of the smaller canals with the larger one are all formed by cut Queenstown limestone and are provided with grooves 5 inches deep and 12 inches wide for stop-planks. There are twenty-five of these connections or inlets in the different parts of the canal, each of which is 14 feet wide and extends to the bottom of the canal. At the mouths of those in use are flat bar iron racks from the bottom to the surface of the water to stop any floating body larger than 1 inch. Ten of these inlets are designed to supply water to ten 5000 horse-power turbines in Power-house Number One of the company. All of the ten small inlets from the large inlet-canal to the side of the wheel-pit slot are connected with the penstocks of the ten turbines. The sides of these canals are 53 feet long and are built of Queenstown stone. Two pairs of grooves are provided for stop-planks near the connection with the large canal, and about 14 feet from the lower end a groove is cut in both sides for the head gate which is operated by hand or electricity. The water of the canal is 12 feet deep at mean low water in the river.

The construction of these elements of the hydraulic system was commenced in August, 1891, and completed in October, 1892, according to the plans prepared by Engineers Clemens Herschel and George B. Burbank.

CHRONOLOGICAL RECORD OF HYDRAULIC DEVELOPMENT AND INSPECTION

The hydraulic system of The Niagara Falls Power Company consisted of a diversion of waters from above the falls, of a small portion of the Niagara River and the development of the power of such waters by their passage along the inlet-canal, down the 130 feet of penstock in the wheel-pit slot, through the turbine wheels and by the 6700 feet of the tail-race discharge tunnel, to the river basin immediately below the Great Falls.

The following records constitute a chronicle of the development of this system, the occurrences that affected its use, and the various efforts made to assure its maintenance, which will be found helpful in considering the problems encountered and the methods adopted for their permanent solution.

October 4, 1890. Tunnel excavation commenced.

December 20, 1892. Tunnel completed.

January 20, 1894. Wheel-pit slot completed.

October 11, 1894. Water admitted.

De Courcy May, engineer in charge, reported:

> It gives me great pleasure to state that the entire work has been evidently thoroughly well constructed and is perfectly satisfactory, with the canal full of water at its normal level.

October 13–20, 1894. Mr. May further reported that:

> the water was drawn off from the canal without any difficulty of any kind and passed through the turbines. I found that the gates, with a full head of water, 12 feet, against them, could be easily raised by one man. I had them opened and shut and they worked most satisfactorily.

April, 1895. First turbo-generator tested and successfully operated.

August 26, 1895. Electrical power first delivered commercially, for use by the Pittsburgh Reduction Company (Aluminum Company of America) in the reduction of aluminum ores.

October 1, 1896. Three 5000 horse-power turbo-alternators in commercial operation, with demand for output exceeding capacity.

November 15, 1896. Buffalo transmission first used commercially for delivery of Niagara power to the Buffalo Railway Company.

June, 1902. During the shut-down for the purpose of removing the bulkhead which separated the tunnel extension to Wheel-pit Slot Number Two from the eastern or upper end of the original tunnel, an inspection was made of the waterways between Wheel-pit Slot Number One and the portal, and all was found in excellent condition.

This shut-down was of special interest by reason of the arrangements that were made to provide the minimum of current required by important customers. The Buffalo Railway Company started up its steam plant and by the reversibility of the distributing and transforming system, the customers in Buffalo and in Niagara Falls received their supply from the steam-driven 600-volt direct-current generators, by reverse process as follows: rotary converters receiving direct current changed it into alternating, which was raised by reversed transformers to 11,000 volts and in that form supplied to the Buffalo distributing system in lieu of current from Niagara. This 11,000-volt current raised by reversed transformers at the Buffalo terminal house to 22,000 volts was supplied to the transmission lines and carried to the powerhouse at Niagara Falls, was there stepped down to 2200 volts, and supplied to customers, and at the end of that period was utilized for synchronizing with the newly started Niagara generators, which thereupon reassumed the load.

If the Buffalo steam plant had been large enough the entire local Niagara Falls load might have been supplied in reversal of the customary procedure, by means of the same links through which just previously the Niagara current had been stepped up as usual from 2200 to 22,000 volts, transmitted over the same wires to the terminal station in Buffalo where it had been stepped down to 11,000 volts, and then distributed to the railway company to be transformed and converted into 600-volt direct current, and to other customers to be stepped down and converted as variously required. Philip P. Barton, superintendent of the Niagara plant, describes his preparations and actions as follows:

> In line with arrangements that had been made to permit the removal of the bulkhead in the tunnel, our local load was reduced at 7 o'clock a. m. on May 31st to approximately 5000 horse-power. All alternators were shut down, with the exception of Nos. 2, 3 and 4 supplying the long distance load and No. 10 supplying the reduced local load, consisting mainly of the railway plant, the local lighting company, about 2500 horse-power to the Castner Company and motors and lights of many of the local tenants. About 6 p. m., in order to reduce still further the water level in the tunnel, the load of the Castner Company was reduced to about 500 horse-power. At 7 p. m. the steam plant of the Buffalo Railway Company picked up 3000 horse-power of the long distance load. The local and long distance loads were put in parallel, Unit No. 9 was started and Units Nos. 2 and 4 were shut down, leaving Units Nos. 3, 9 and 10 to carry the remaining load.
>
> At 1 a. m. on the 1st inst., the remnant of the local load was shut down and the long distance load was reduced to a point where it could be carried by the steam plant of the Buffalo Railway Company.
>
> The steam driven 500-volt generators of the Buffalo Railway Company were paralleled with the rotary converters on the direct current side. Alternators Nos. 3 and 9 had already been shut down and the speed and voltage of Unit No. 10 were gradually reduced until the steam plant had taken practically all the load. The 22,000-volt circuit breakers in the terminal house were then opened, thus leaving the steam plant driving direct-current generators, which supplied current to the rotary converters, running them as direct-current motors. The current from the alternating current end of these converters was supplied to the low voltage coils of the transformers which were thus transposed from step-down to step-up transformers, charging the cable system with 11,000-volt current. This was transmitted to the Wilkeson Street Station, where, as usual, it was stepped down and transformed to meet the various requirements of the Buffalo General Electric Company. In this way a large portion of the load of the Cataract Power & Conduit Company was supplied without the slightest disturbance in continuity.
>
> As soon as the Buffalo load was cut off, the alternator switch on Unit No. 10 was opened and the power-house lights were transferred to the circuits supplied from the Canadian power-house. The kodak outfit had previously been started and was supplying the arc lights, and the exciters and air compressor were then shut down. The only machinery left running in the power-house was one of the rotary exciters supplied from the Canadian plant to furnish power for the traveling crane in Power-house Number Two.
>
> At 7:24 a. m., notice was received from the Construction Department that the work in the tunnel had been completed. The water-driven air compressor and the two turbine exciters were immediately started and while the large penstocks were being filled, the

22,000-volt circuit breakers in the terminal house were closed, thus charging the transmission line through the terminal house transformers from the 11,000-volt cables supplied from the steam plant. 22,000-volt current was thus brought to our step-up transformer house where it was stepped down and delivered to our bus-bars at 2200 volts. The ultimate object of this procedure was to furnish current for the Lincoln synchronizer, so that one of our generators might be synchronized with the steam plant in Buffalo. This was done successfully as soon as the first generator was ready to start. The load was then transferred from the steam plant to this generator, and Niagara power was once more delivered in Buffalo without any break in the service, so far as many of the users in Buffalo were concerned. The first generator was synchronized with the Buffalo steam plant at 7:35 a. m., just eleven minutes after notice to start had been received. Two minutes later the first machine was connected with the local load. Direct current was delivered to the railway circuits in Tonawanda at 7:50 a. m. and Lockport was notified to take load at 8 a. m. Direct current was supplied from the local railway plant at 8:05.

The entire plant in shutting down and starting up was handled skillfully and promptly by the electricians in charge under the immediate supervision of Mr. Giboney. There was a delay in shutting down of about twenty minutes due to the manipulations required in Buffalo in transferring the load without interruption from Niagara power to the steam plant. The only mishap incident to the entire proceeding was the burning of the General Electric direct-current circuit breaker on No. 2 railway converter panel caused by defective working of the breaker when opened at 1 a. m. preparatory to shutting down the railway plant. The main result of this was some spectacular fireworks, the actual damage being very slight.

The arrangements made and carried out for transferring a considerable portion of the Buffalo load to a steam plant for a few hours and then transferring it back again without interruption of service are interesting as an illustration of the flexibility of our long distance distributing system. With a steam plant in Buffalo of sufficient capacity, it would be possible not only to supply the important Buffalo tenants but to send to Tonawanda, Lockport and Niagara Falls all the power required to operate the interurban trolley lines and for other purposes.

June 14, 1908. To enable the International Railway Company to inspect the abutment of its steel arch bridge adjacent to the portal of the American tunnel, both the American power-houses were completely closed down for five hours, and the wheel-pit slots and tunnel were drained. Careful inspection at that time developed that the wheel-pit slots and the tunnel between Wheel-pit Number One and the portal, about 1½ miles, were in excellent condition. The stockholders were duly informed, February 16, 1909, of these matters, in part as follows:

In the tunnel extension the lining was found broken in the roof in two places: one near the junction with the original tunnel, where a few bricks had fallen, the other near the junction with Wheel-pit Number Two, at which point a portion of the roof had fallen for some distance. It was evident that the injuries had existed for some years, and it was subsequently determined by our engineers that the primary cause of the breaks was squeezing due to rock pressure that occurred after the tunnel brickwork was completed, and doubtless that was occasioned by blasting in the unfinished excavation of Wheel-pit Number Two. Preparations for repair work were begun immediately, and on July 19th both power-houses were again shut down, Number Two remaining inactive until the full completion of the repairs on August 2nd; Number One being operated between July 28th and the night of August 1st, Wheel-pit Number Two and the adjacent part of the tunnel meantime being shut off by a temporary bulkhead.

Advance information of these shut-downs, with an invitation to inspect the tunnel and wheel-pits, having been given to the International Waterways Commission and to the United States Lake Survey, both bodies availed themselves of the opportunity for examination and careful measurements and of otherwise securing data in respect of the amount of water diversion and of the effect of this diversion upon lake and river levels and upon the scenic beauty of the falls.

This invitation was fully availed of for a period of ten days beginning July 19 and ending August 2, 1908. It is stated in the report of November 30, 1908, by Major Charles Keller, that the opportunity was used with gratifying success.

The details of these observations are given in Chapter VIII, entitled "The Shut-downs of The Niagara Falls Power Company," pp. 37–44; Chapter IX, "Effect on Lake Erie," pp. 44–49; Chapter X, "Effect on Niagara River above the Upper Rapids," pp. 49–52, and Chapter XI, "Effect on Rapids and Falls," pp. 52–56, of the Report of Francis C. Shenehon, principal assistant engineer, commencing on page 18 of Major Keller's report to the chief of engineers, United States Army, printed in *Preservation of Niagara Falls*, Message of the President, Senate Document No. 105, Sixty-second Congress, First Session, 1911.

All necessary power deliveries during these two shut-downs were continued, without interruption, from the Canadian plant and from available surplus power of The Electrical Development Company of Ontario, Limited.

In the report of W. Edward Wilson, secretary of the American section of the International Waterways Commission, attached to the Fourth Progress Report of that body to the United States Secretary of War, dated December 1, 1908, it is stated that the effect of the aggregate diversion of the two power companies on the American side was a lowering of the surface of the river at the crest of the American Falls (Prospect Point) to the extent of 0.032 foot, about 3/8 of an inch.

A. H. Van Cleve, consulting engineer, in charge of the repairs of 1908, reviews in his report[1] of August 5, 1908, the theories as to the principal cause of damage to the tunnel lining and concludes as follows:

> I believe, therefore, that as the destructive forces have now ceased to act, we may have a comfortable assurance as to the future stability of the tunnel.

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[1] Appendix J, Volume II.

July 10, 1921. The head gates at the two Niagara plants were shut down at 12:30 a. m. for about five hours, for the purpose of inspecting the wheel-pit slots and the tunnels, and particularly of ascertaining the condition of the tunnel downstream from the shaft at Erie Avenue, where the rock excavated from the adit of the new pressure tunnel to the Hydro Station 3-C had been dumped through shaft Number Two into the main discharge tunnel.

Inspection of Racks on Inlets from Canal to Turbine Penstock, in Power-house Number One. (A. C. Douglass[1] in Diving Suit.)

None of the rock which had been dumped down the old Erie Avenue shaft was found in the tunnel. Scratches through the thin, oily, slippery film that covered all the brick linings, showed where the rock dumpage had been carried away into the river. The brick lining had not been injured or disturbed.

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[1] Anthony C. Douglass, 1855–1922, mining engineer and contractor on inlet-canal, wheel-pit, and its tunnel. Mayor of city of Niagara Falls, 1907–1911.

The brick and other masonry work in the wheel-pit slots and tunnels were reported to be in perfect condition.

Because of the repairs found necessary when the tunnel was examined in June, 1908, where the water discharged from the wheels of Power-house Number One met the waters from Wheel-pit Number Two and the ice currents from the ice shaft, careful examination was made at this time of the state of the masonry between Wheel-pit Slots Numbers One and Two, and the roof and sides of the tunnel near the ice shute connection.

Anthony C. Douglass, contractor, marked X.

Rock Excavation in Wheel-pit Slot of Power-house Number One Showing Group of Construction Men and Engineers, March 13, 1892

No injuries or disturbances were found and the inspection party, all competent for this investigation, agreed in pronouncing the entire underground water system to be in fine condition.

The slimy covering of the interior surface of the tunnel is considered an advantage as it protects the surface of the brick and stone of the walls from the friction of the ice and other substances brought along by the swiftly moving current and facilitates their passage with a minimum of abrasion.

WHEEL-PIT SLOT NUMBER ONE

At the bottom of the wheel-pit in Power-house Number One for 34⅝ feet in height are massive brick walls which line the wheel-pit in the top of the shale rock and carry the cross-girders that support the penstocks and wheel-casings. At the top of the wheel-pit from the floor of the power-house down to durable rock the sides are lined with stone masonry in which are built the skew-backs for stone arches under the dynamos.

These arches have a span of 21 feet and a rise of 5.8 feet, or a radius of 12.4 feet, and at the time they were designed it was expected that the stationary parts of the dynamos would weigh 90 tons. This, with the allowance for stone foundations for the dynamos, made a very heavy load on the crown of the arches. In addition to this it was necessary to make an opening 5 feet in diameter through the crown for the shaft of the turbine. Two of the three arches built are 20½ feet long and the third one is 22 feet long. The great weight of these arches and their loads has a purpose, for were there any vibration in the fast running dynamos it would be absorbed by the mass of the supports and would not become perceptible.

In arranging the designs for the construction of the wheel-pit slot and the installation of the turbines, it was considered necessary not only to establish proper relations of hydraulic slope with the main tunnel, but, because of the novelty of the undertaking, to allow ample space for changes in the machinery and modifications or additions in construction in the wheel-pit. The turbines were therefore placed for safety before maximum efficiency, believing that such precaution, even if proved later to have been unnecessary, was nevertheless a good risk to take. Draft tubes, now in use, were not employed in early turbine construction.

The wheels were located above the probable reach of back-water from the main tunnel, thus avoiding the drowning of the turbines and interfering with the operation of the wheels by the flooding of the wheel-chambers.

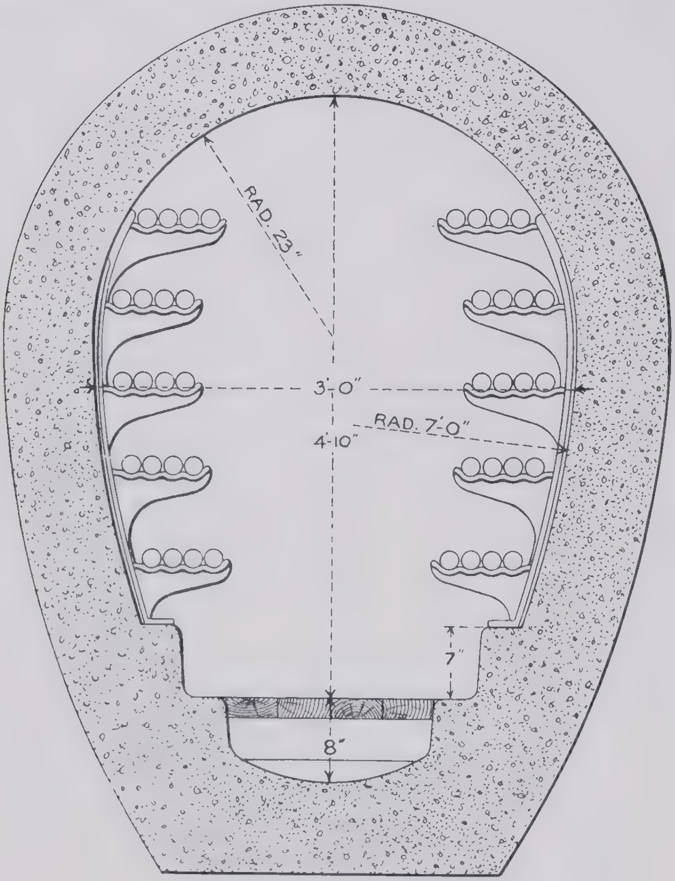
It was also deemed important to provide safe access to any of the turbines for their examination without being obliged to shut down other turbines.

CABLE SUBWAY AND CONDUIT

The distribution of electricity for local use was made from the transformer-house by means of a tunnel of concrete, of horseshoe shape, with the heel at the base. On the inside, iron brackets were placed on each side of the tunnel, each bracket to carry in grooves four lead-covered copper conduits, as shown by the following section of the subway.

A wooden platform over a drain provided a convenient access for inspection of the cables. This tunnel was constructed for about 2000 feet, at the end of which the cables were raised to the arms of a wooden pole aerial line for extensions as were required.

In extending the local distributing system in 1899, it was found advantageous, in order to avoid possible damage and interruption, to substitute for the subway a conduit of concrete containing thirty-six 3-inch ducts, as shown herewith.

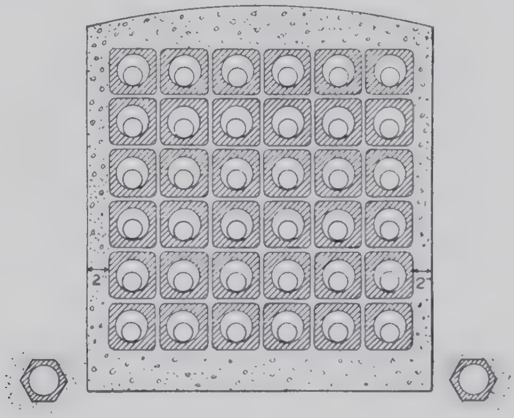


Cross-section of Subway

By the use of this arrangement of cables, important losses were avoided by reason of the lead sheaths being grounded in the subway tunnel and in many cases in contact with each other. The cost of construction, including manholes, was reduced about one-half by the conduit. This form of transmission, largely, if not altogether, prevented an accident by one cable damaging its neighbor and avoided the possibility of cables being violently thrown about by the repulsive effects of heavy short circuits, as had frequently happened in the tunnel.

A short circuit at the transformer-house of the Pittsburgh Reduction Company,[1] nearly one-half mile distant from the power-house was sufficiently violent to throw one of the lead covered cables, about 1½ inches in diameter and weighing approximately five pounds per foot, from its iron bracket completely across the cable subway, 3 feet wide, where it was found transferred to the next lower bracket on the opposite side of the subway for practically its entire length of 2000 feet.

While it was more difficult in some instances to locate a fault in cables in conduits, this disadvantage was considered fully offset by the less danger that a short circuit in one pair of cables would involve other cables, as was the experience with the subway system.



Conduit

HYDRAULIC MAINTENANCE

The maintenance of a hydraulic system above described, in many respects unique and particularly so in the quantities of natural products excavated and those utilized, required close observation for unexpected phenomena and especially for weaknesses and strains from natural and artificial pressures.

The operations of the system were intended to be continuous, night and day.

Many uses could not be observed while the operations continued, and possible results were considered danger points in the maintenance problem until examinations disclosed the full effects of operation and the possible requirements ascertained and provided that would assure continuity of power development and distribution.

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[1] Now Aluminum Company of America.

ROCK EXPANSION AFTER EXCAVATION

The unexpected development of expansion in the freshly excavated walls of the tunnel, while under construction, commanded watchful attention to the geological formations in which the hydraulic system had been constructed.

The geological formation in which the three wheel-pit slots are excavated consists of 10 feet or so of glacial drift overlying a dark gray dolomite about 150 feet thick under which is a soft bluish gray argillaceous shale.

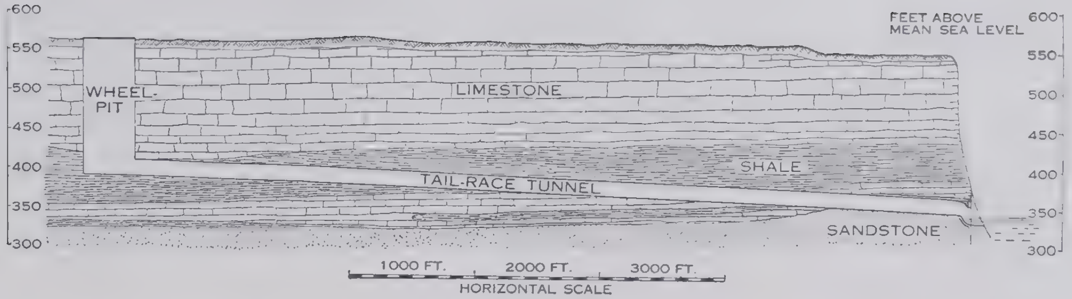
Wheel-pit Slot Number One containing the ten turbines which were first installed required an excavation 20 feet wide by 425 feet long with an average depth of 182 feet. Wheel-pit Slot Number Two and that of the Canadian Niagara Power Company have been constructed by similar excavations.

The accompanying diagrams show in section the rocks above mentioned as well as other rocks exposed in the Niagara Gorge. The relation of one of the wheel-pit slots and the tail-race tunnel to the rock formations is indicated as well as the stratification at the portal of the tunnel.

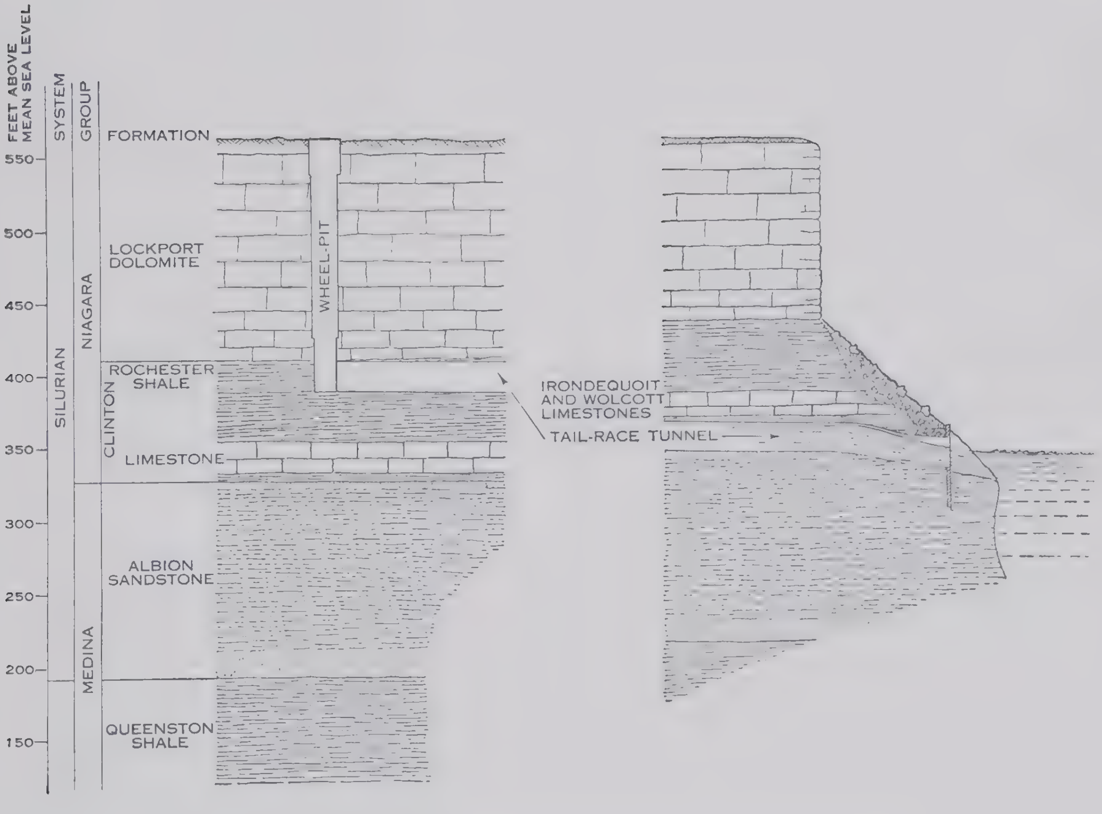
The Lockport dolomite forms the rocky brink of the Niagara Gorge throughout much of its length and is the rock over which the water falls. The massive layer of dolomite strongly resists the erosive effects of the water, but the softer underlying rocks at the base of the falls are more quickly worn by the impact of the falling water and by the action of the air and frost where exposed above the surface of the pool below the falls. By the wearing away of the soft shale the harder layers are undermined until the overhanging masses of dolomite and limestone break off and fall into the pool below.

The question of the stability of the walls of a long deep excavation would naturally confront any engineer undertaking work of such character. Fortunately there was nature's example to draw conclusions from, for at several places in the gorge as well as under the falls, as just referred to, the walls are vertical or overhanging to a marked extent. One would therefore come to the conclusion that if protected from the erosive action of the elements the wheel-pit walls should stand for many years.

However, upon the completion of Wheel-pit Slot Number One in 1900, to the dimensions of 424 feet in length, 17 feet in width, and 178 feet in depth, it was discovered that the side walls were perceptibly moving inward, slightly bending the beams and girders which were placed across the pit for the purpose of supporting the machinery. Steps were promptly taken to stay the movement by means of heavy blocks of masonry placed between the side walls at points between the turbines, also by means of heavy cast-iron braces at other points wherever they would not interfere with the operation and maintenance of the machinery.



Sectional View of Wheel-pit and Original Tail-race Tunnel Showing Stratification of the Rocks Through Which the Tunnel Was Built



Sectional View of the Stratification at the Wheel-pit and Portal of Tunnel

The President reported to the directors at their meeting, December 28, 1897, that the movement of the walls of the wheel-pit slot had stopped, that there had been no indication of movement since August 15, 1897, and that the total cost of strengthening and lining the original wheel-pit slot and its extension for the complete equipment of ten hydro-electric units, would probably not exceed $125,000.

It was with no little anxiety that the officers of the company viewed the movement and there was great relief when it subsided and could only be detected by careful measurements.

Subsequent experience has shown that the greater part of the movement occurred during and shortly after the completion of the excavation, depending more or less upon the amount of blasting going on in the vicinity and was undoubtedly due to the relieving of internal stresses generally existing in the earth's surface.

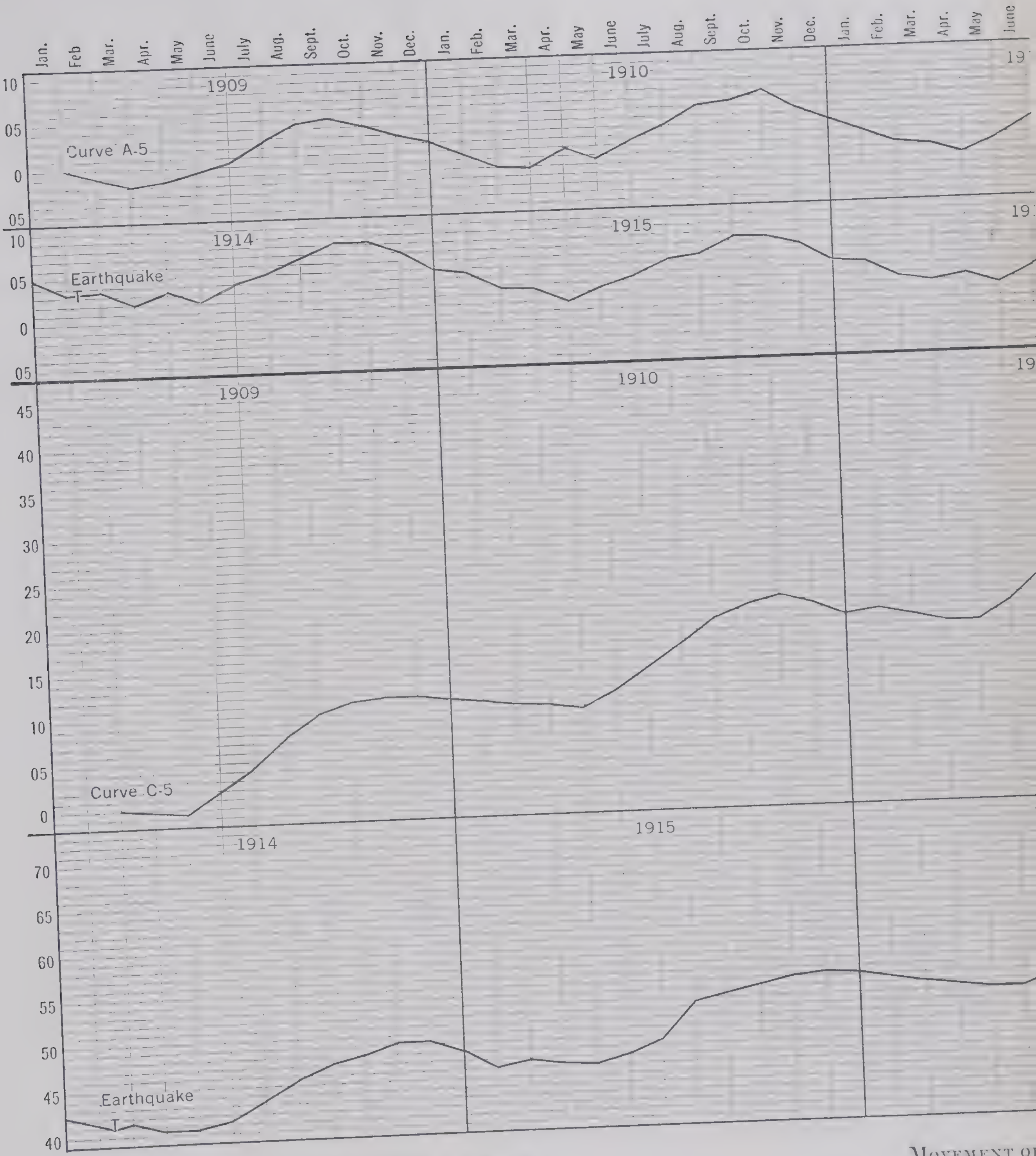
Just how much the walls moved while the excavation was under way is not known. The maximum movement observed since the completion of the lining of the wheel-pit slots is about 4 inches measured just below the turbine deck near the middle of the Canadian wheel-pit slot. There has also been some upward movement observed at the bottom of the Canadian wheel-pit slot.

A method of regularly measuring the movement of the walls was instituted at an early date. It consisted of measuring between rods or pins about 1 inch diameter set opposite each other in the side walls of the pit.

A measuring bar consisting of a steel tube of known length and somewhat shorter than the distance between the pins was held, one end against one pin, while the space between the end of the bar and the second pin was measured by inserting a graduated glass wedge. This method served the purpose so long as there was an appreciable movement, but after the walls reached a nearly stable condition the movement became so small that the method was found to be too crude.

In 1908 a new measuring apparatus illustrated on page 53 was devised which had the following improvements:

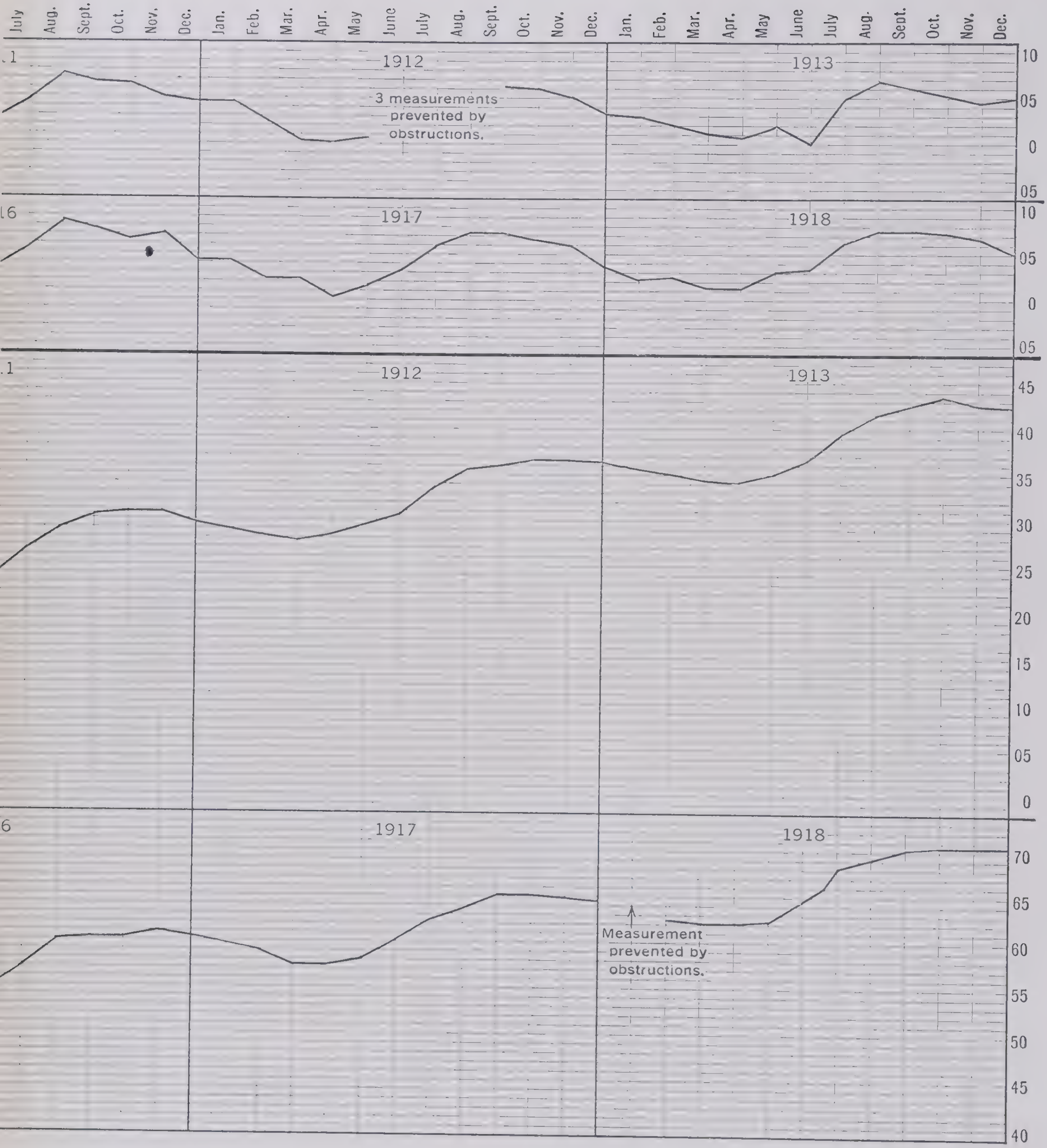
(1) The pins were provided with hard bronze tips to avoid error from the rusting of steel tips; (2) the measuring bar was designed so that it is automatically held in the same position and with the same pressure against the pins after being laid upon them; (3) a screw type micrometer capable of measuring to 0.0001 inch is used; (4) length of measuring bar is corrected for temperature at time of measurement; and (5) the apparatus can be handled by one man.



Upward movement indicates narrowing of wheel-pit
Downward movement indicates widening of wheel-pit

MOVEMENT O

Curve A-5: Niagara Plant.
Curve C-5: Canadian Niag



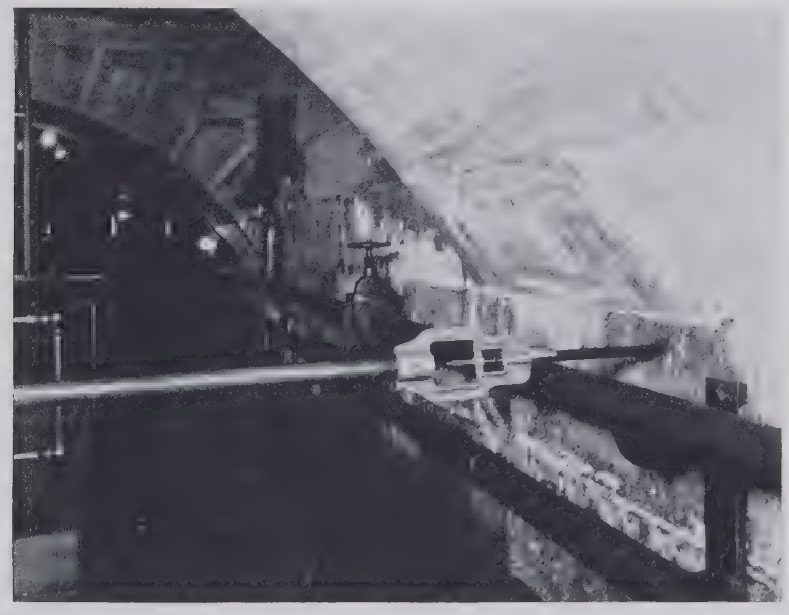
EEL-PIT WALLS

-pit Number One, Thrust Deck

wer Company, Turbine Deck

Movements are indicated in units of one-thousandths of an inch

Since January 1, 1909, measurements made once each month at several points in all of the wheel-pit slots have been recorded and plotted in curve form. Two curves which are typical of the others are herewith reproduced. Curve A-5 shows the movement of the walls near the middle of Wheel-pit Slot Number One at the thrust deck and Curve C-5 near the middle of the Canadian wheel-pit slot, at the turbine deck. Measurements at the middle of the wheel-pit slots are chosen for illustration because it is there that the movement is generally the greatest.



Measuring Instrument of 1908 for Determination of Expansion and Contraction of Wheel-pit Walls

It is to be noted that no positive movement of the walls of Wheel-pit Slot Number One has occurred in the last nine years, but there is a seasonal variation in the width of the pit of about 0.06 inch which is equivalent to about 1⁄16 of an inch. The pit is widest in April and narrowest in September. The conclusion to be drawn is that the walls expand in the summer and contract in the winter due to seasonal variations in the temperature of the atmosphere which has been observed to be between 32 and 80 degrees Fahrenheit. Similarly it is to be quoted that Curve C-5 shows a seasonal variation in width of about 0.07 inch which is slightly more than 1⁄16 of an inch and that a positive narrowing of about 0.7 inch or nearly 3⁄4 of an inch has occurred since January 1, 1908.

When the first three generating units were installed in Wheel-pit Slot Number One the various steel beams and girders spanning the pit for the purpose of supporting various parts of the machinery and the floors had their ends bedded in the walls. The movement inward of the walls resulted in a slight buckling of both beams and girders and those most affected were, as a matter of precaution, replaced. In order to prevent a recurrence of the damage another method of support was adopted consisting of supporting the beams on the upper horizontal surfaces of projecting cast-iron brackets which were bedded in concrete in the walls so that they could slide one upon the other should undue pressure be exerted by the walls. Similarly the turbines and the lower elbows which form the supports for the penstocks are carried upon heavy cast-iron brackets. At first it was customary not only to bolt the machinery and penstock elbows to the brackets, but also to key them on both sides to avoid any possible disturbance of their alignment. The keys had to be cut out from time to time when the effects of the squeezing action became apparent. Later the plan of keying to the brackets on only one side of the wheel-pit slot was adopted so that by simply slacking off the bolts on the other side the compression is relieved and the bolts are again tightened. On account of the precautions taken no damage of any note has resulted.

The horizontal struts or columns which have been referred to as having been placed across the wheel-pits to stay the movement of the walls are considered of doubtful value and have been omitted in the extension of the Canadian wheel-pit. Apparently the inward movements continued between the columns and their effect was only local and had apparently ceased at about the close of the year 1907.

The subject of the movement of the side walls of the wheel-pit slot was submitted for examination and report to Prof. J. F. Kemp, geologist, and Messrs. Olcott, Fearn and Peele, mining engineers, as expert engineering consultants.

Reports with plans and recommendations were also prepared by Messrs. Sellers, Herschel, Brackenridge, and Kuichling, of the company's board of engineers at that time.

The board of directors of the company, on July 28, 1897, authorized the strengthening of the walls of the then wheel-pit slot and its full extension, according to plans submitted, by the construction of masonry walls or supports and struts between each two units of turbine machinery; the side walls were increased 4 inches in thickness.

MATERIALS AND MEN

In the construction of the main tunnel, inlet-canal, wheel-pit slot and power-house, the greatest number of men employed at any one time was about 2500.

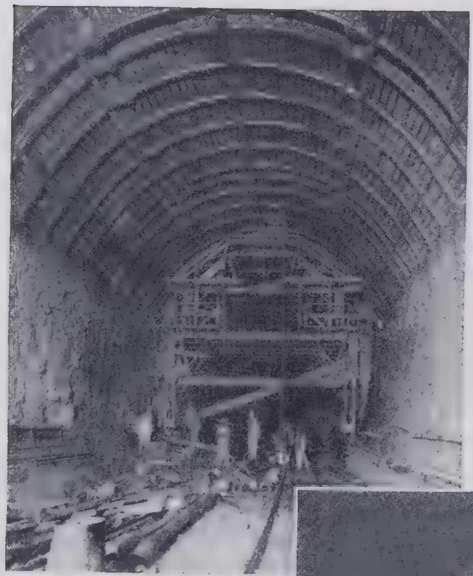
The material removed amounted to 600,000 tons. The principal materials used comprised 16,000,000 bricks; 19,000,000 feet of timber and lumber; 60,000 cubic yards of stone; 55,000 barrels of Portland cement; 12,000 barrels of natural cement; and 26,000 cubic yards of sand.

JOHN GREEN EDWARD D. VERY
TUNNEL ENGINEERS DURING CONSTRUCTION

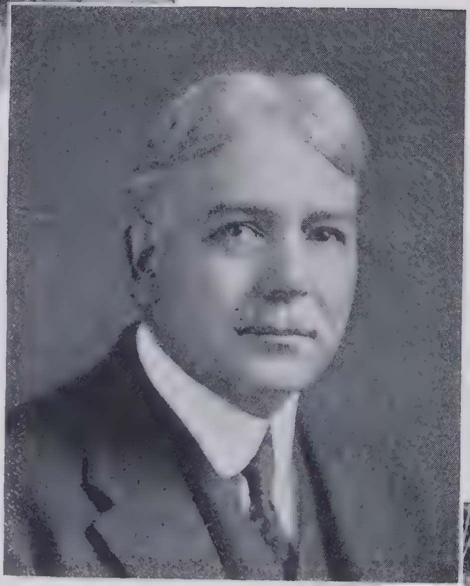
A systematic record of the progress of the work was made by photographs taken by members of the engineering corps of all construction above ground.

A general idea of the conditions from time to time, under ground, was also recorded by photographs of selected points of special interest.

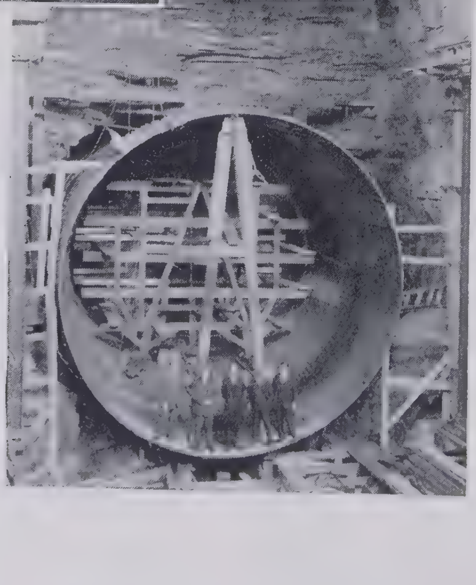
The two members of the special corps of engineers, whose duty it was to be on call, day and night, to give the necessary lines and grades for the tunnel boring and also for the timber lining are shown above.



Pressure tunnel extending from hydraulic canal to Power Station 3-C, 1922.

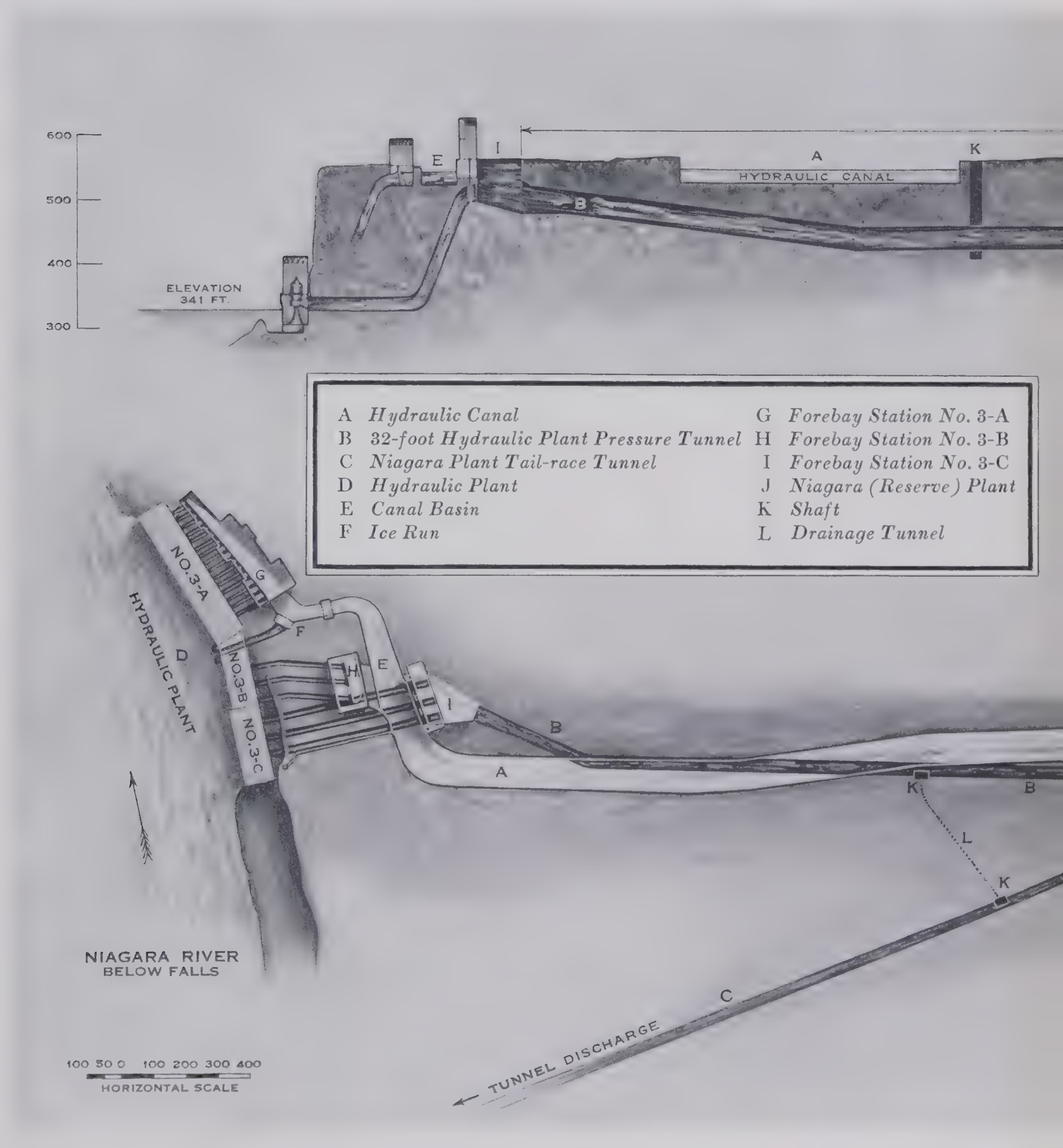


John Lyell Harper (1873–1924), vice-president and chief engineer of The Niagara Falls Power Company, designer of the pressure tunnel.



Penstock outlet, 70,000 horse-power turbines, in Station 3-C, 1922. Figures from left to right: Gibson, Harper, Johnson, Dales, and Bernstein.

CONSOLIDATE
I
OF THE NIAGARA F

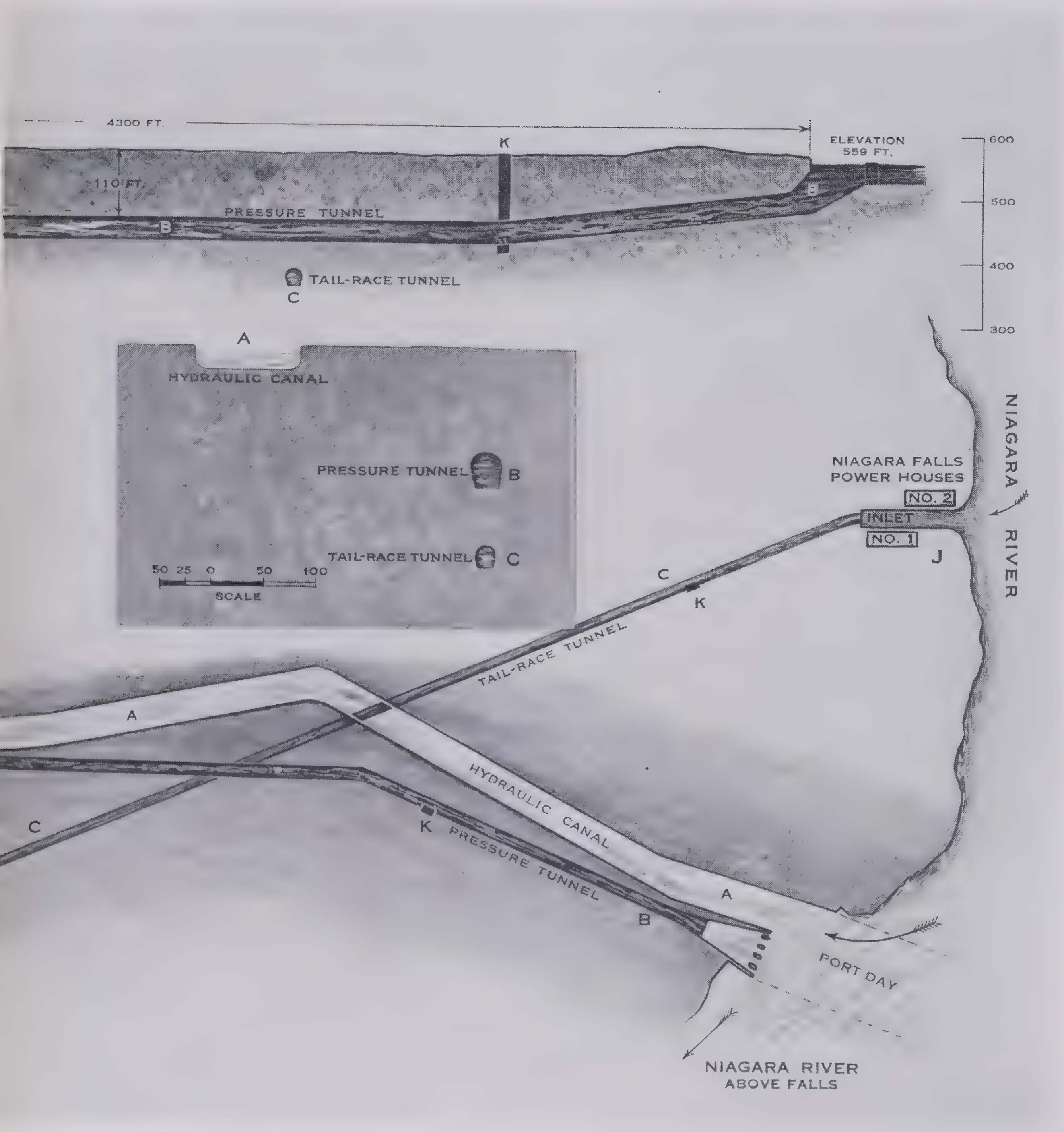


A	*Hydraulic Canal*	G	*Forebay Station No. 3-A*
B	*32-foot Hydraulic Plant Pressure Tunnel*	H	*Forebay Station No. 3-B*
C	*Niagara Plant Tail-race Tunnel*	I	*Forebay Station No. 3-C*
D	*Hydraulic Plant*	J	*Niagara (Reserve) Plant*
E	*Canal Basin*	K	*Shaft*
F	*Ice Run*	L	*Drainage Tunnel*

1847 Hydraulic Plant
A *long* intake canal A, and a *short* outlet D

1895 Niag
A *short* inlet-canal and

WATERWAYS
925
LLS POWER COMPANY



RA PLANT
ong discharge *tunnel* C

1923 HYDRAULIC PLANT
A *long* intake tunnel B, and a *short* discharge I

PROFILE CROSS-SECTION AND PLAN OF WATERWAYS OF THE NIAGARA FALLS POWER COMPANY

MCMXVIII

comprising the two hydraulic systems acquired by consolidation in 1918, subsequently enlarged in 1923, by construction of a pressure tunnel under and practically parallel with the canal, a distance of about 4300 feet

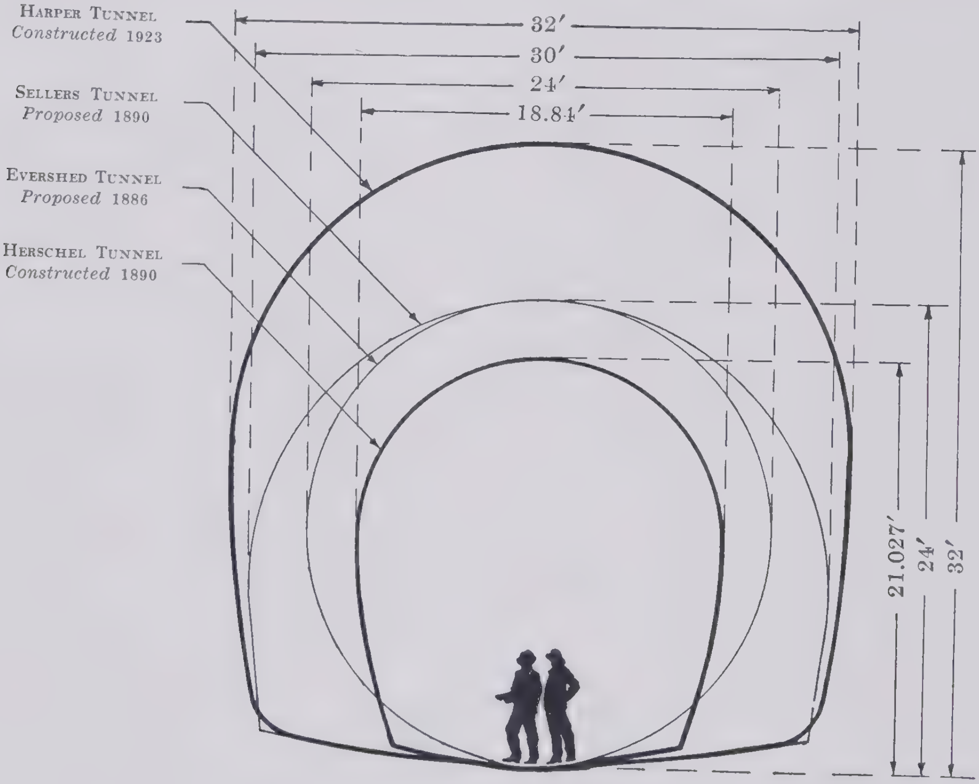
Hydraulic Canal, opened 1857, from Port Day, on Niagara River above the falls to a canal basin on the bluff, and that has since supplied the forebays for Stations 3-A and 3-B, on the river bank below, with hydro-electric machines of 245,900 horse-power capacity.

Tail-race Tunnel of Niagara Plant discharging the water from 21 turbines, of 115,500 horse-power capacity, located in Power-houses Number One and Number Two, the latter completed in 1904, on an inlet-canal from the Niagara River above Port Day; the tunnel passing more than 100 feet below the hydraulic canal to the portal discharge into the river below the falls.

Pressure Tunnel of Hydraulic Plant, in operation 1923 from Port Day on Niagara River, passing 45 feet over the discharge tunnel from the upper river plant, and 110 feet under the hydraulic canal, 4300 feet, to the forebay of Power Station 3-C, located below the bluff on the river bank, where three hydro-electric units of 70,000 horse-power each, a total of 210,000 horse-power, are in operation.

THE PRESSURE TUNNEL

On March 2, 1921, three years after the consolidation of the Hydraulic Power Company of Niagara Falls and The Niagara Falls Power Company to form The Niagara Falls Power Company, MCMXVIII, the Federal Power Commission issued a license giving to the consolidated company the right for fifty years to use all the water permitted to be diverted above the falls on the American side of the Niagara River. This license, the first to be issued by the Federal Power Commission also gave formal approval to plans already developed by the company for reserving Power-houses One and Two for "stand-by" service and employing the water in a second extension to Hydraulic Station 3-C.



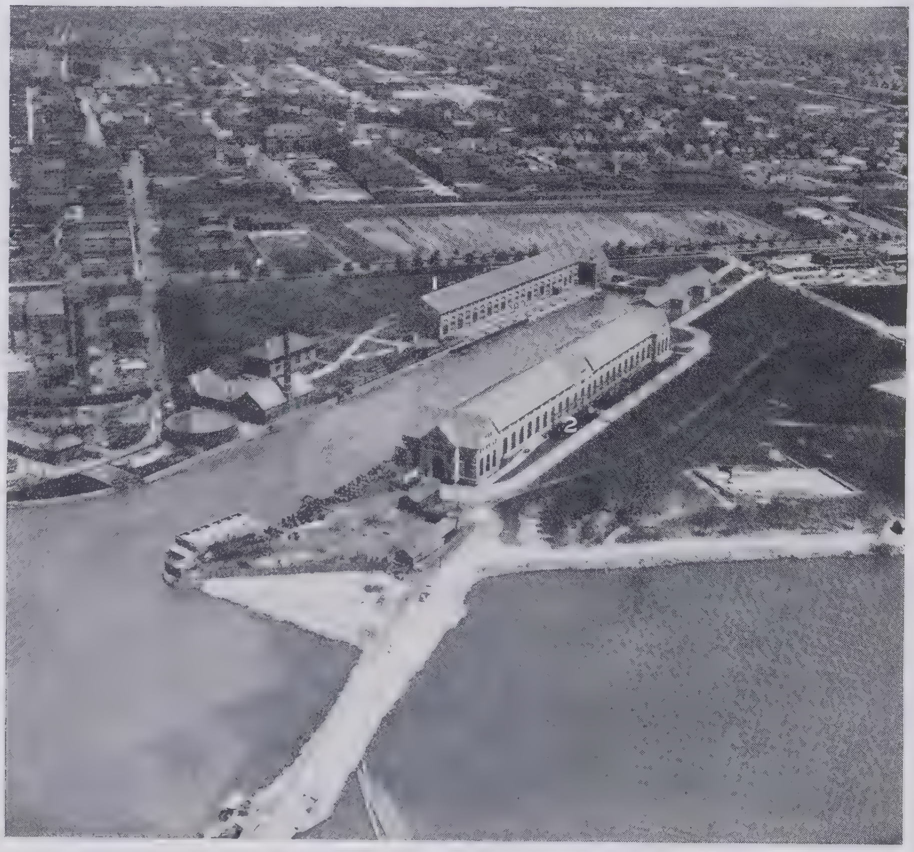
COMPARATIVE CROSS-SECTIONS OF TUNNELS CONSIDERED

To deliver this water at the proposed new plant a pressure tunnel was adopted. The tunnel was designed by John Lyell Harper, vice-president and chief engineer of The Niagara Falls Power Company, MCMXVIII, for a capacity of 10,500 cubic feet of water per second at a velocity of 12 feet per second. It is cut in solid rock and is concrete lined throughout its entire length of 4300 feet. The insert (pages 57–58) indicates the course of the tunnel and its grades and also shows its proximity to the canal and to the discharge tunnel.

Comparing the cross-sections of the discharge tunnel, indicated on the diagram on page 60 as the "Herschel Tunnel" of 1890, with the "Harper Tunnel" completed in 1923, we see that the discharge tunnel is of horseshoe form, 21 feet high and 18 feet 8 inches in maximum width, while the pressure tunnel of similar form, is 60 feet high and 60 feet wide at the intake portal, decreasing in cross-sectional dimensions, 150 feet from the portal, to 32 by 32 feet.

POWER-HOUSES AND THEIR USE

CHAPTER XVIII



Inlet-canal, and Power-houses Numbers One and Two of
The Niagara Falls Power Company,
1925

POWER-HOUSES AND THEIR USE

CHAPTER XVIII

ARCHITECTURE

AT a time when all new construction at Niagara Falls was considered from the point of view of the interest of the public in conserving the scenic beauties of the Great Falls and of its islands and river banks, so recently acquired by the state and set apart as its reservation for the enjoyment of its citizens and their visitors, the erection of a conspicuous structure on the river bank, within view of the reservation, became a question for the careful study of public sentiment as well as of architecture.

THE POWER-HOUSE

It should be different (from others)—not a mill over a water-wheel with its old time mill-race and tail-race, but the housing of the torrents of Niagara, driven in its harness to hidden depths, where divested of its mighty power it speeds like a flash to distant use, long before its tail waters can return to their normal flow.

It should be *attractive,* artistic in grandeur, dignified, impressive, enduring and monumental. The souvenir pictures carried away by the visitors should include one or all three of the power-houses.

The climate was well known as severe in the winter season. The records of low temperature, fierce storms sweeping down from the Arctic North, across the lakes and along the river, with snow and ice, were familiar to the residents and thought by many to presage difficulties in hydraulic operations, to secure for continuous manufacturing, the power of the overwhelming current.

The power-house should be *protective,* invite confidence and afford shelter.

The project was admitted to be very different from previous efforts to harness the mighty power. The monster water-wheels were buried far out of sight in the native rocks and although it was officially declared the diversion of the water from the falls "would not affect the depth of water flowing over the falls to an extent that would be visible," the public—like the visitors to the Centennial Exhibition in Philadelphia in 1876 who "wanted to see the wheels go 'round"—would manifest a similar but greater interest at Niagara and wish to see the "harness" of the great cataract. The visitors wished to understand the process, know what became of the water diverted, and how it would be possible to translate the water-power into an electric power that would escape to Buffalo unseen, over simple wires, and there move the pumps of that city's water-works, the trolley cars in its streets, and take the place of steam engines in its factories.

The power-house should be *instructive* and afford a demonstration and an exhibition.

Here were three important considerations in the design of the power-house; it should be attractive, protective and instructive.

Although the building must of necessity be large, proportionate to the amount of power to be developed, and probably, in due time, to be duplicated, it should express in its design the purpose of its construction.

By the use of the native stone, as the oldest inhabitant had recommended by building his own home of that material, and keeping the surface of the stone roughly trimmed, the character of the structure would be defensive, as against the storms without, and protective of the valuable machinery enclosed therein.

Provision should be made for the admission of the public without danger to themselves and without interruption to the service, and for intelligent and helpful guides who would explain the methods of utilization and distribute the literature provided. Each visitor should learn enough to desire to know more, and should be impressed by the evidence that the managers of the enterprise had confidence in the investment of their own capital, and had built for endurance and continuity of operation.

Messrs. McKim, Mead and White, architects, of New York, were requested to prepare plans for the power-house and its conduit bridge and transformer-house, according to the foregoing requirements and such as might be determined by the board of engineers of the company in connection with the installation and operation of the hydraulic and electrical machinery provided.

The general lay-out of the power-house location is indicated upon the diagram on page 19, which also shows the location of the second power-house and the provisions therein of a covered forebay found necessary to exclude ice and to admit water from below its normal level in the power canal.

Above ground the stone Power-house Number One had a length of 200 feet when first constructed, that was increased to 450 feet when ten turbines were installed in the wheel-pit. The eaves are 40 feet from the ground, and the ridge is 20 feet more. Circular topped windows 14 feet wide and 15 feet 2 inches high are recessed in the thick walls of the building. The tops of these recesses are elliptical arches formed with very long voussoirs. These arches with the circular ones over the windows are one of the striking features of the building, which is so well proportioned that a stranger does not estimate the parts nearly so large as they are. The width of the building is 69⅔ feet except for 43⅔ feet deep on the front, where the administration office of the company makes a width of 102 feet.

HEATING BY ELECTRICITY

The heating of the power-house was a subject of conferences in the autumn of 1894. The architects included chimneys in their preliminary plans for the building. Some of the directors thought a comprehensive heating system requisite because of the climatic conditions that made inside heating necessary to protect the operatives from the Arctic conditions without, in the long winter season.

Electric heaters on the scale required in so large a hall as that of the power-house were not then commercial. One estimate was that 700 horse-power would be required to heat the house electrically. Having confidence that the ten alternators would provide all the heat required when they were in full operation, and that therefore the want was a temporary one that should be supplied without delay and in an inexpensive manner, Paul M. Lincoln, superintendent of electrical construction of the company, was requested to consider the matter with the purpose of providing the heating wanted. At his suggestion the power-house was equipped with a number of heater coils that were suspended above interference on each side of the power-house. They were made of iron wire, of the proper size and length to give the necessary electrical losses for heating the plant, and were operated directly by the 2200-volt current of the alternators. As now recalled, the wire coils were about 3 feet in diameter and 5 to 6 feet in height, and because of their dangerous potential were raised above the reach and possible injury to the attendants or visitors. The device was successful and continued in use until the heat from the increased number of machines in operation rendered them no longer necessary. These coils might have been given a place in a museum of scientific appliances as one of the earliest instances where heaters were operated at so high a voltage, but they were scrapped and no photographs retained by a grateful staff.

The administration offices were heated by the small electric heaters that were then available in the market for electrical supplies.

FOUNDATION CONSTRUCTION

The views on pages 68 and 69 show various stages of the construction of the wheel-pit slot and the power-house.

WHEEL-PIT SLOT

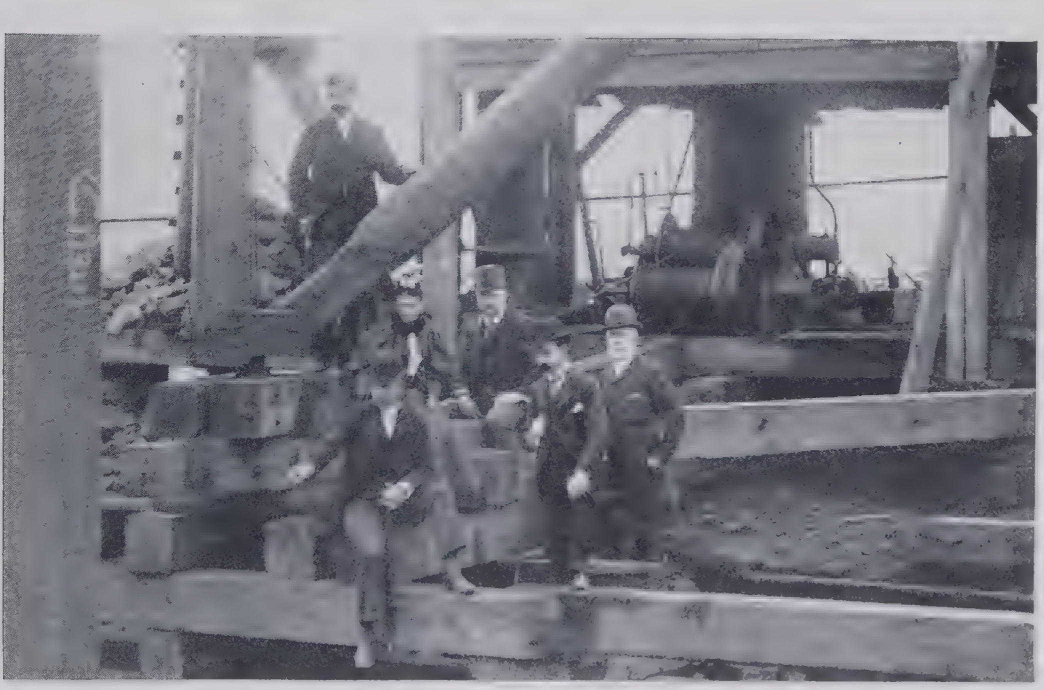
One of the problems resulting from the Evershed project, to utilize so large an amount as 200,000 horse-power, was that of the wheel-pits; how to arrange them with their water conduits and ample space for factories. By long-established custom, each factory was located as near as possible, generally directly over the pit containing the water-wheel or by its side, in order to make the shortest possible connection between the source of power and the machines for its use. Estimating the maximum power requirements as 500 horse-power for each factory, a wheel-pit was designed that contained four wheels, one at each corner of a square shaft, with an elevator in the middle for service and inspection, and a single surface conduit, surrounding the large shaft or pit with the water at the top to be supplied to each wheel as required. This method is outlined by the plan shown in Chapter XVII. The location and construction of four separate factories and their railroad facilities under these conditions were inconvenient and impracticable on the large scale of power use proposed, although it reduced considerably the necessary excavations of water conduits by combining four pits in one.

Excavated Slot, August 21, 1893

View from Above

TRANSFORMER-HOUSE

On the east side of the inlet-canal is the stone transformer-house 90½ feet long and 39 feet wide with an extra width of 17⅔ feet for 28⅔ feet at the present south end. The center of this 28⅔ feet will be the center of the building when it is completed should more room be needed. This building is 21½ feet to the eaves and 32 feet to the ridge, and similar in appearance to that of the power-house designed by the same architects. Connecting the power-house with the transformer-house is a 10-foot wide stone bridge of four spans each 25.87 feet long with a rise of 3.47 feet and stone piers 5⅓ feet long between the ends of the spans. These arches have the long voussoirs which characterize the power-house and the transformer-house.



INSPECTION OF WHEEL-PIT SLOT CONSTRUCTION BY

COL. THEO. TURRETTINI
Foreign Consulting Engineer

MRS. EDWARD D. ADAMS

EDWARD A. WICKES
Vice-president

GEORGE B. BURBANK
Resident Engineer

EDWARD D. ADAMS
President

DR. COLEMAN SELLERS
Chief Engineer

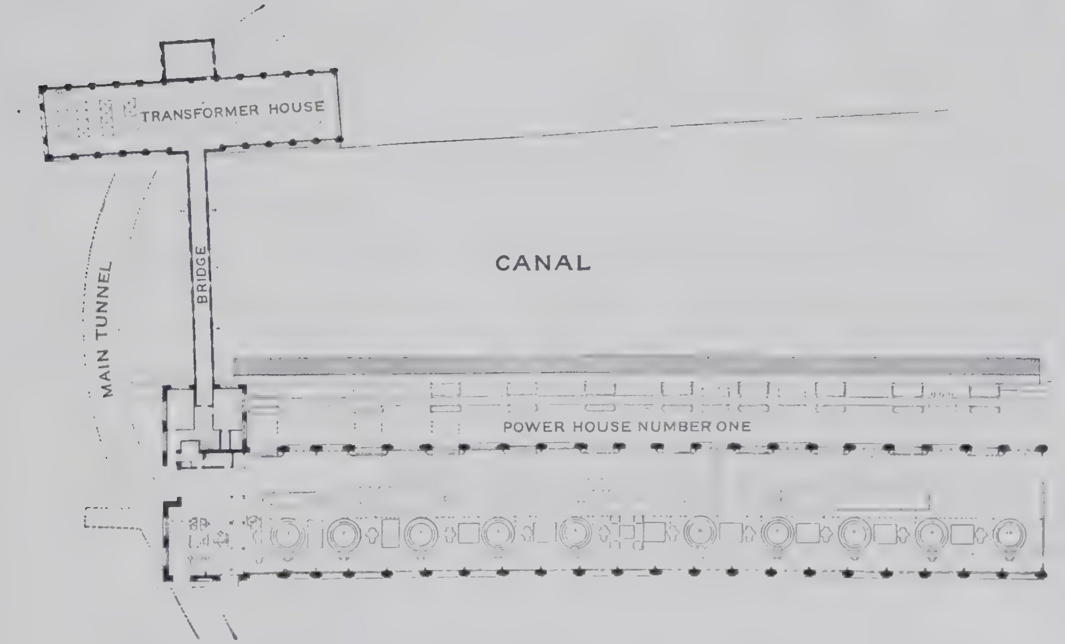
In adopting the plan of a central power-house and distributing the power to users at convenient distances, it was a natural development to place all the water-wheels together in line on the side of the only inlet-canal and discharging into a common outlet connecting with the main or discharge tunnel.

Power-house Number One. Construction of Penstock

The arrangement of the power-house, bridge and transformer-house, in relation to each other, and the location of the machinery are shown on opposite page.

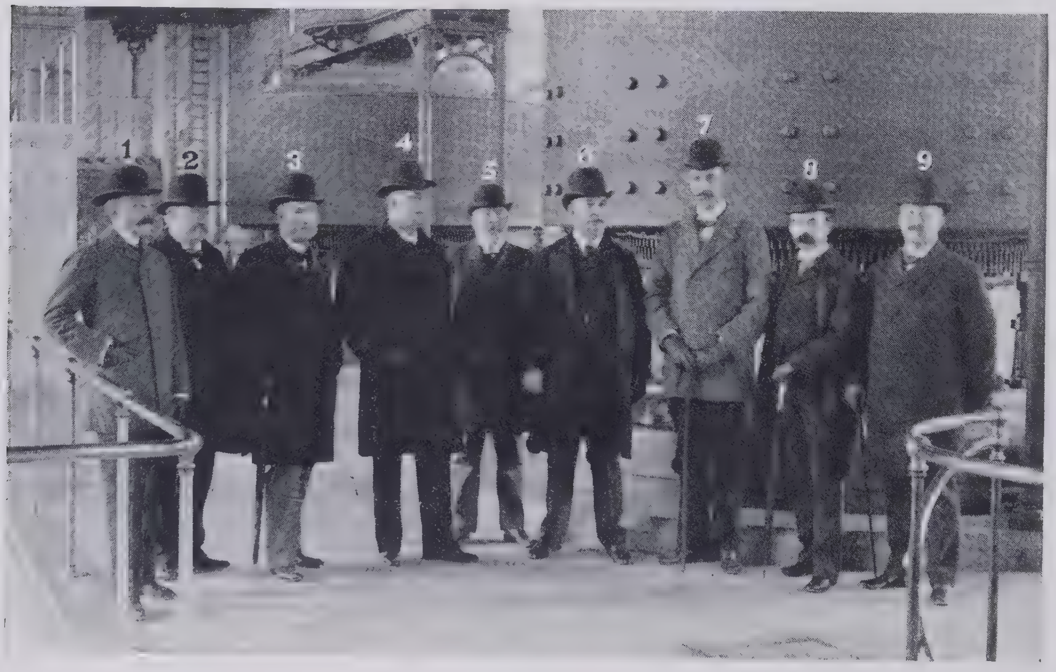
This elongated wheel-pit became a wheel-pit slot, and its dimensions were the minimum proportions of the power-house to cover it and of the hydro-electric machinery and its auxiliary provisions for its installation and operation.

The Exterior of Power-house Number One



Plan of Power-house Number One and Its Auxiliary Structures

The directors of The Cataract Construction Company made their official inspection of the power-house and the operation of the first power unit on September 30, 1895, as will be seen by the following view of the interior of the power-house.



Interior of Power-house Number One, September 30, 1895
Hydro-electric Unit Number Two in Operation

Board of Directors of The Cataract Construction Company standing from left to right:

1. *William B. Rankine, Secretary*
2. *Edward A. Wickes, Vice-president*
3. *Darius O. Mills*
4. *George S. Bowdoin*
5. *John Crosby Brown*
6. *Charles Lanier*

   Committee Representing the "Money Subscribers"

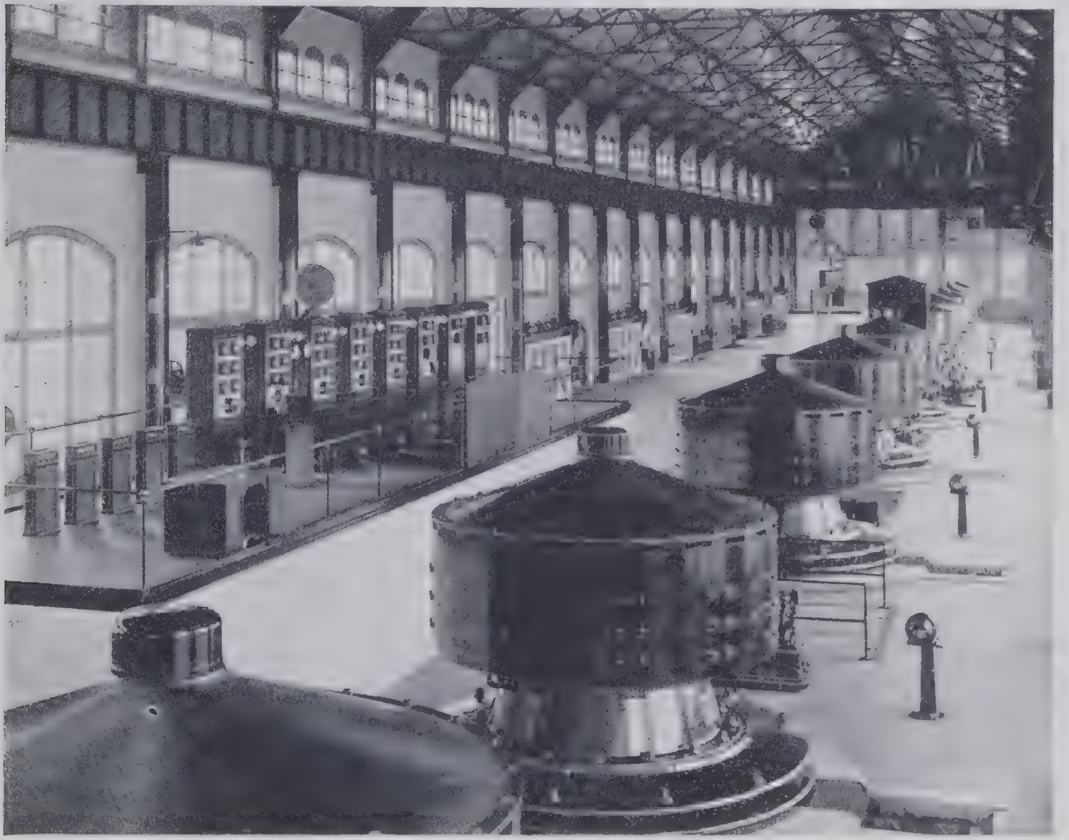
7. *John Jacob Astor*
8. *Edward D. Adams, President*
9. *Francis Lynde Stetson, Vice-president*

The first contract with the Westinghouse Company, for two alternators, was made October 26, 1893. The first hydro-electric unit was successfully tested in

April 1895, and the first delivery of electric power was made on August 26, 1895, to the Pittsburgh Reduction Company.[1]

After the successful operation of the two power units shown opposite, additional units were purchased and the power-house and wheel-pit slot extended to provide for ten complete units, all of the same design as the first.

This installation, pictured below, was completed September 30, 1899, and on January 1, 1900, was in full operation, the ten machines earning operating expenses and a surplus over the fixed charges of the company.



Interior of Power-house Number One

ELECTRICITY NOT COMPRESSED AIR FOR POWER-HOUSE NUMBER TWO

When the decision was first made to construct central power-houses, provision was made for two of 50,000 horse-power each, that would utilize nearly all the water the inlet-canal would provide, in addition to that required for the International Paper Company and the Niagara Water-Works Company, each having independent water-inlets from the canal. As the decision had not then been made to adopt the alternating current of electricity, the management was prepared to provide a direct current, for power and light, from the first power-house for local uses principally. The second power-house was planned for the development and distribution of compressed air for power uses, unless all the electricity produced at Power-house Number One should be used and the additional demand in prospect should indicate that all the power of the inlet water would be wanted for electric power transmission.

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[1] Name changed to Aluminum Company of America.

Exterior of Power-house Number Two

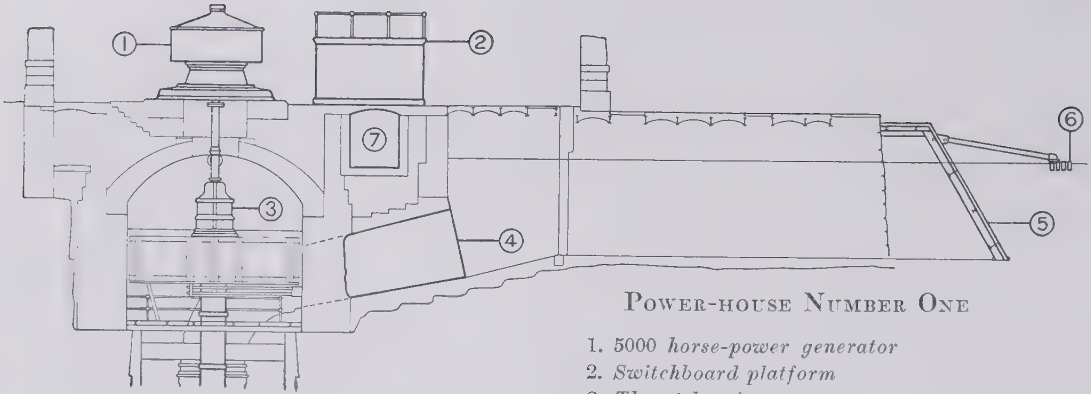
The question, so important to this enterprise, as to the method of utilizing the waters of Niagara River, was decided by resolution of the board of directors, on May 6, 1893, in favor of the alternating current. From that date all plans were directed toward this form of electrical development and transmission, so that the provision for a possible compressed air system was abandoned, and no other methods were given further consideration.

Some time prior to the completion of Power-house Number One, the demand for electric power had so greatly increased that contracts were made for Power-house Number Two on the opposite side of the canal, and for a practical duplication of the machinery installed in Power-house Number One, but with eleven units, Unit Number 21 to be treated as a reserve. The hydro-electric Unit Number 11 in Power-house Number Two was started October 31, 1902, in commercial service, and the entire plant was in operation, March 16, 1904.

Interior of Power-house Number Two

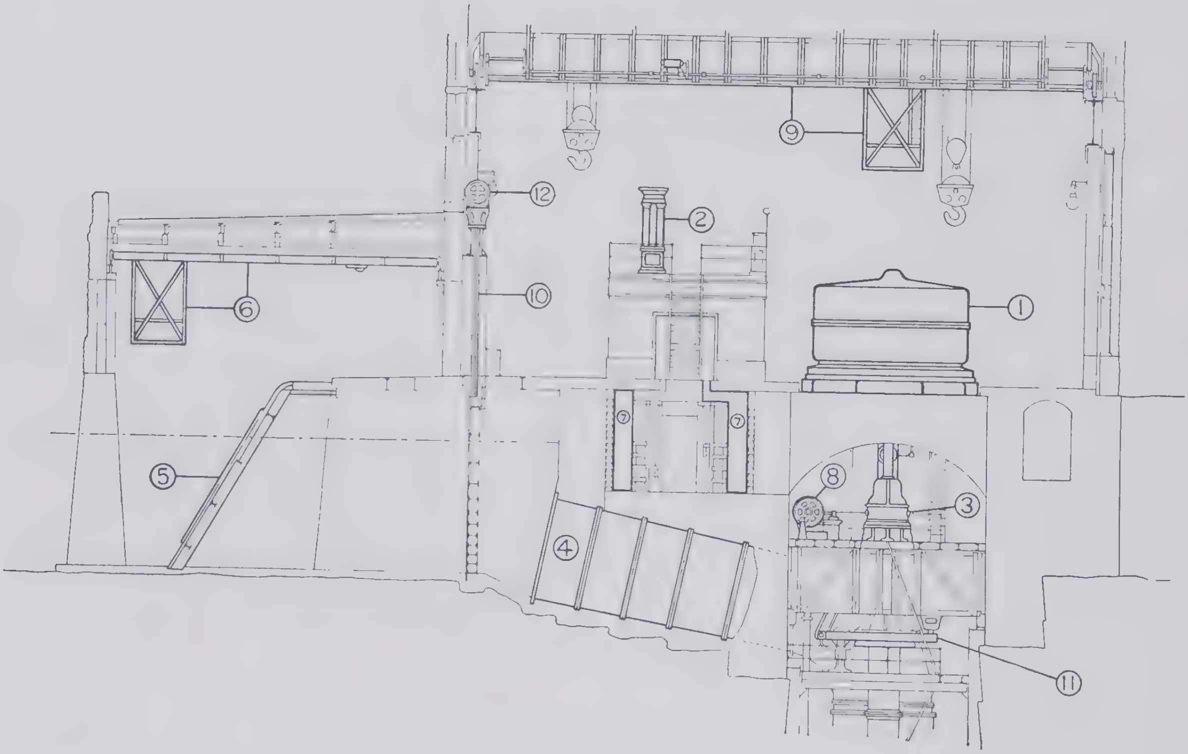
PROJECTS FOR ADDITIONAL POWER

Indications in 1902 that the new metallurgical and chemical processes would require a larger demand than the installed machinery (with a capacity of 65,500 horse-power and a prospective additional 30,000 horse-power to be



Power-house Number One

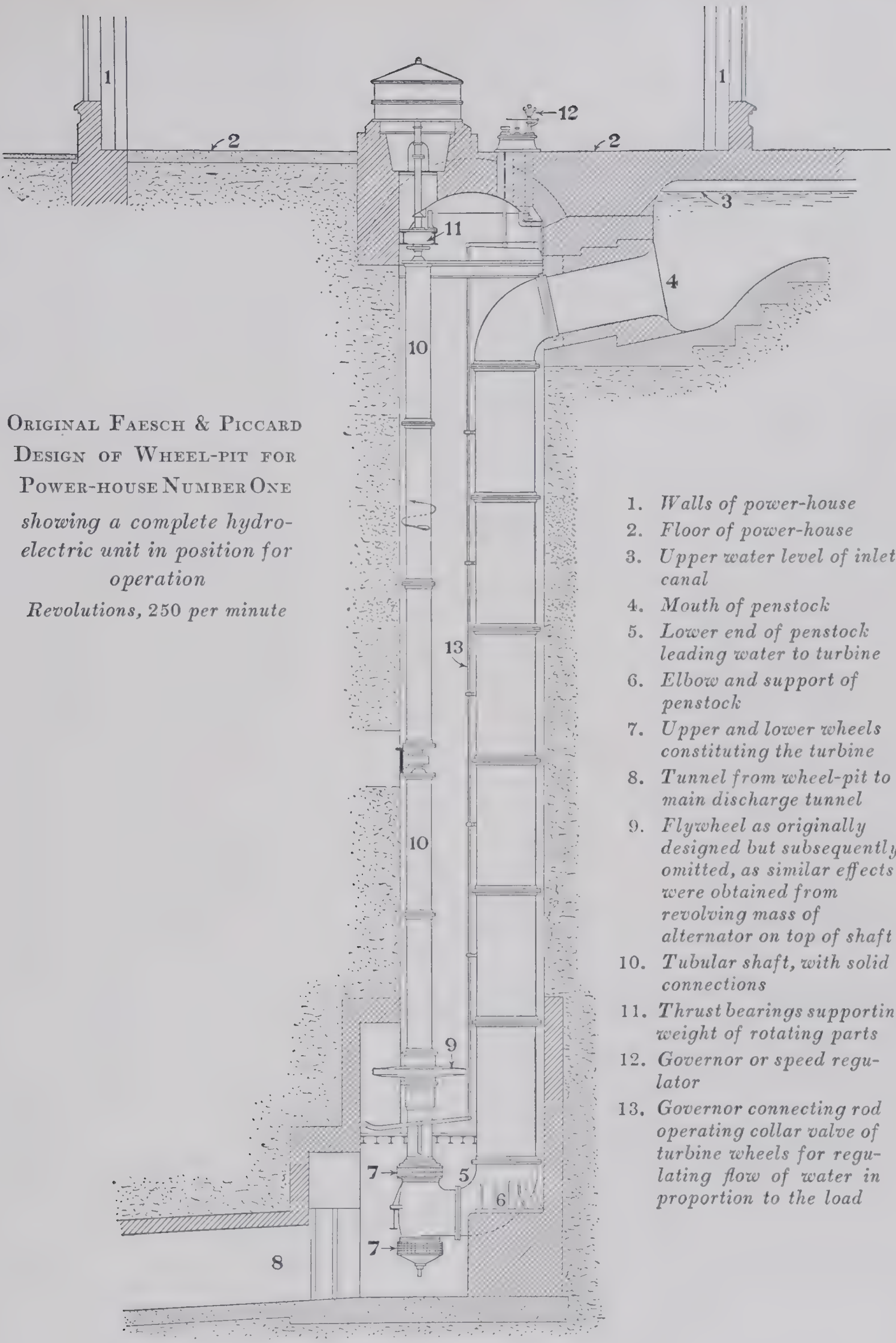
1. *5000 horse-power generator*
2. *Switchboard platform*
3. *Thrust bearing*
4. *Penstock mouth*
5. *Intake rack*
6. *Ice boom*
7. *Cable subway*



Power-house Number Two

1. *5000 horse-power generator*
2. *Switchboard*
3. *Thrust bearing*
4. *Penstock mouth*
5. *Intake racks*
6. *Traveling crane*
7. *Cable subway*
8. *Oil pump for thrust bearing*
9. *Traveling crane*
10. *Head gate*
11. *Brake*
12. *Head-gate motor*

Cross-section Diagram of Machinery in Power-houses Numbers One and Two



ORIGINAL FAESCH & PICCARD DESIGN OF WHEEL-PIT FOR POWER-HOUSE NUMBER ONE *showing a complete hydro-electric unit in position for operation*

Revolutions, 250 per minute

1. *Walls of power-house*
2. *Floor of power-house*
3. *Upper water level of inlet-canal*
4. *Mouth of penstock*
5. *Lower end of penstock leading water to turbine*
6. *Elbow and support of penstock*
7. *Upper and lower wheels constituting the turbine*
8. *Tunnel from wheel-pit to main discharge tunnel*
9. *Flywheel as originally designed but subsequently omitted, as similar effects were obtained from revolving mass of alternator on top of shaft*
10. *Tubular shaft, with solid connections*
11. *Thrust bearings supporting weight of rotating parts*
12. *Governor or speed regulator*
13. *Governor connecting rod operating collar valve of turbine wheels for regulating flow of water in proportion to the load*

available in 1903) could supply, prompted The Niagara Falls Power Company to purchase the Canadian Niagara Power Company, represented by its share and debenture capital outstanding, for the purpose of availing of its franchises, rights and privileges that gave it a most favorable location for its power-house within the Queen Victoria Niagara Falls Park, under the terms of agreements with the park commissioners made April 7, 1892, July 15, 1899 and June 15, 1901.

Before consummating the contemplated purchase of the Canadian company, The Niagara Falls Power Company requested that an estimate be made by its expert engineers as to the probable cost in time and money to construct an independent hydro-electric system, by using its existing right-of-way for a second tunnel, under the town of Niagara Falls to the river below.

This right-of-way for a second tunnel was acquired in 1890, when the rights to construct the first tunnel were secured, had been held with title unimpaired, with the expectation of making use of it when the capacity of the first tunnel, its inlet-canal and the two power-houses approached their full capacity of about 105,000 horse-power.

GRASS ISLAND POWER-HOUSE AND TUNNEL PROJECT

The increase in the cost of tunnel construction, on a right-of-way about twice the length of the first tunnel, led to the consideration of locating the third power-house upon Grass Island near the shore of the company's property, a short distance east of its inlet-canal.

It was proposed to locate and acquire the right-of-way for a new tunnel, passing under lands of private owners, west of Second Street, and discharging into the lower river at a portal lot about 260 feet north of the discharge of the original main tunnel. The resident engineer, A. H. Van Cleve, submitted his estimate, dated April 15, 1904, of the cost of development of 110,000 horse-power in Wheel-pit Number Three, with tunnel, having sufficient capacity for the relief of Wheel-pits Numbers One and Two, that amounted to $6,826,000, being at the rate of $62.05 per horse-power. This estimate included, with other necessary expenditures—tunnel and shafts, $1,678,000; wheel-pit and forebay, $1,330,000; power-house, including foundations, $548,000; and hydraulic installation, $1,394,000. To the total estimate it would have been necessary to add the cost of the right-of-way, legal expenses and possible transmission lines. The total expense involved in the construction of the Grass Island project appeared so large that the suggestion reached no further than the period of preliminary estimate.

CANADIAN PROJECT

The purchase of the Canadian interests for the sum of $345,000, payable in the bonds of The Niagara Falls Power Company, and the estimated cost to construct the plant under the terms of its charter and agreements, with a capacity to produce 100,000 horse-power, indicated at considerably less cost, in time and money, than that of the Grass Island project.

Moreover, the addition of a Canadian source of power and a Canadian transmission line to Buffalo, as a duplicate plant to that of The Niagara Falls Power Company on the American side, was considered of much value as a supplemental supply available for that city and beyond, the existence of which plant under the same control and management, would go far to establish confidence in the continuity of the supply of power service to the industries and the communities of a large and important portion of the United States which nature has favored so richly beyond all others. As the authority had been secured to connect the proposed Canadian power-house with the two power-houses on the American side by conduits across the suspension bridges over the Niagara River with a current of 50,000 horse-power at 2000 volts, a distance of about 2½ miles, the power developed on each side might be used as a reserve in case of need, as well as an additional supply for the necessities or opportunities for use on the other side. Therefore, the purchase was made and the alternative Grass Island project still lies dormant.

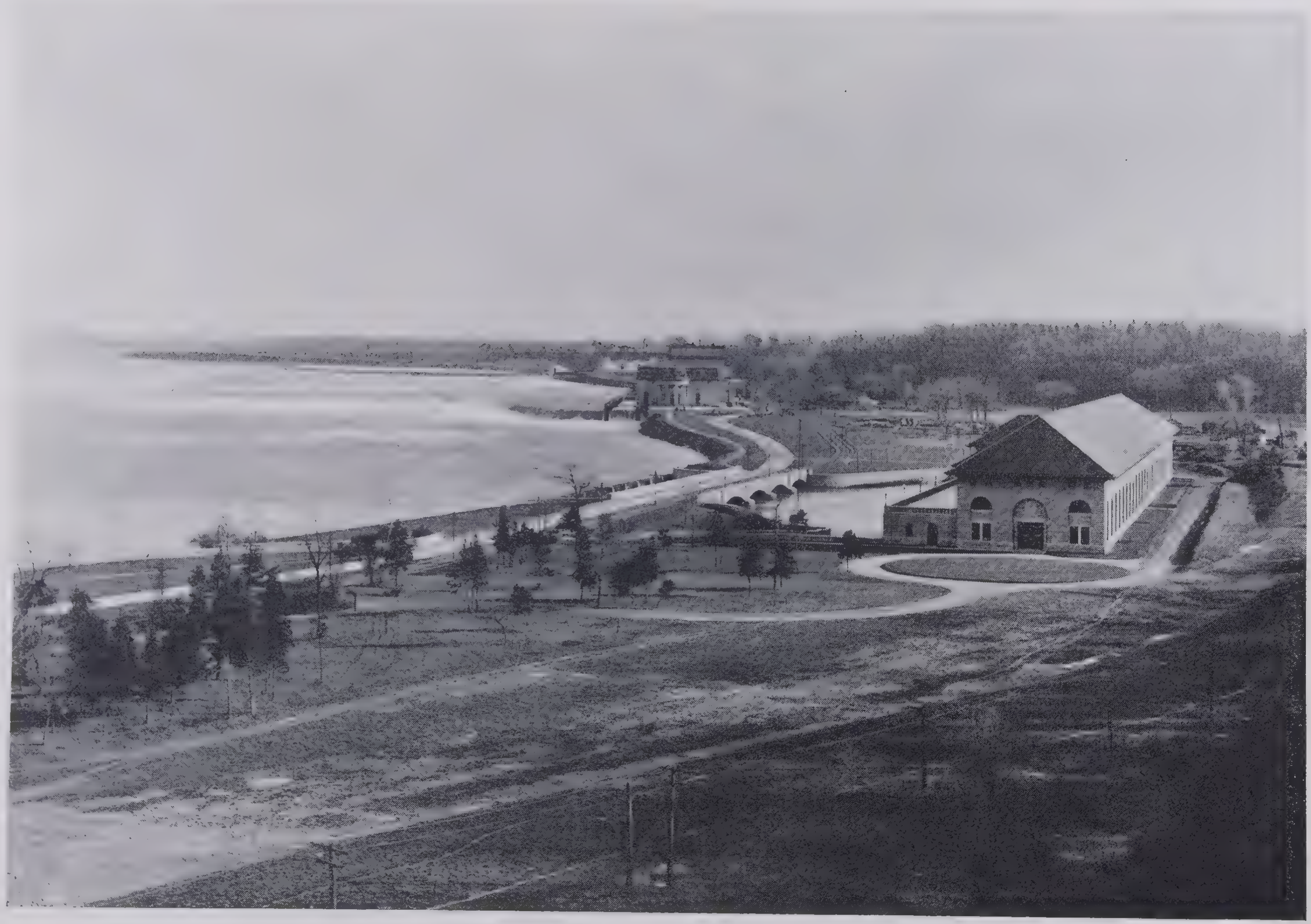
THE CANADIAN NIAGARA POWER COMPANY POWER-HOUSE NUMBER THREE AND UPPER RAPIDS

The Canadian Niagara Power Company, American owned, was the first on the Canadian side of Niagara River to receive a franchise, and it was the pioneer company in Canada to furnish Niagara hydro-electric power for commercial uses.

Work was commenced on the excavations for the outlet tunnel, forebay, wheel-pit and foundations of the Canadian power-house on May 23, 1901, and on January 1, 1905, the first alternator of 10,000 horse-power was in commercial operation.

The hydraulic work and the entire power-house were completed in 1906, constituting the Canadian plant and Power-house Number Three of The Niagara Falls Power Company, that has been in continuous operation since 1905, with increasing output of electrical energy, reaching 104,960 horse-power and continuing above 100,000 horse-power output since 1916.

The seven power-stations of the present Niagara Falls Power Company, MCMXVIII have an installed capacity of 678,500 horse-power. The three

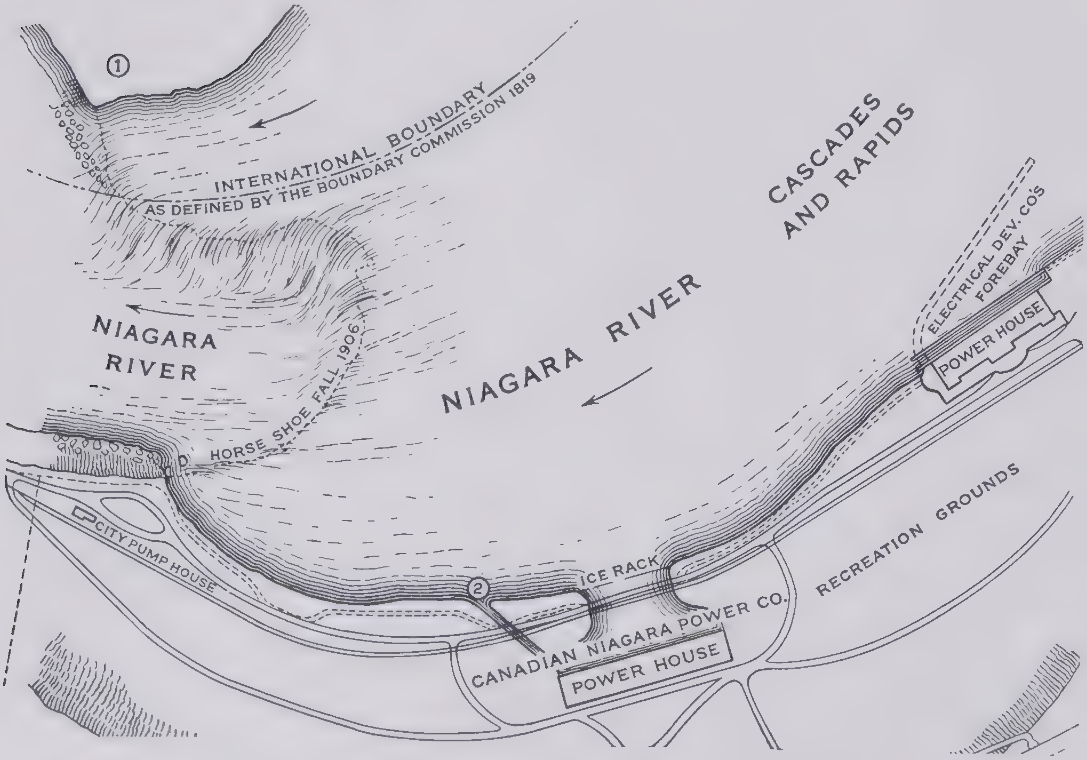


View of Canadian Upper Rapids and Canadian Power-house Number Three, in Queen Victoria Niagara Falls Park, 1913 power-houses described in this chapter have an installed capacity of 226,000 horse-power, and one of these, the Canadian Niagara plant, is located in the Queen Victoria Niagara Falls Park. Two other plants of later construction in this park area, the Ontario Power Company and the Electrical Development Company, with large and imposing power-houses, were subsequently (1917) acquired and are now operated by the Hydro-Electric Power Commission of Canada, representing certain Ontario municipalities, leaving the power-house of the Canadian Niagara Power Company the only plant in the Queen Victoria Niagara Falls Park operated by private owners, The Niagara Falls Power Company, MCMXVIII.

Canadian Power-house, 1913

Wheel-pit Construction, 1904

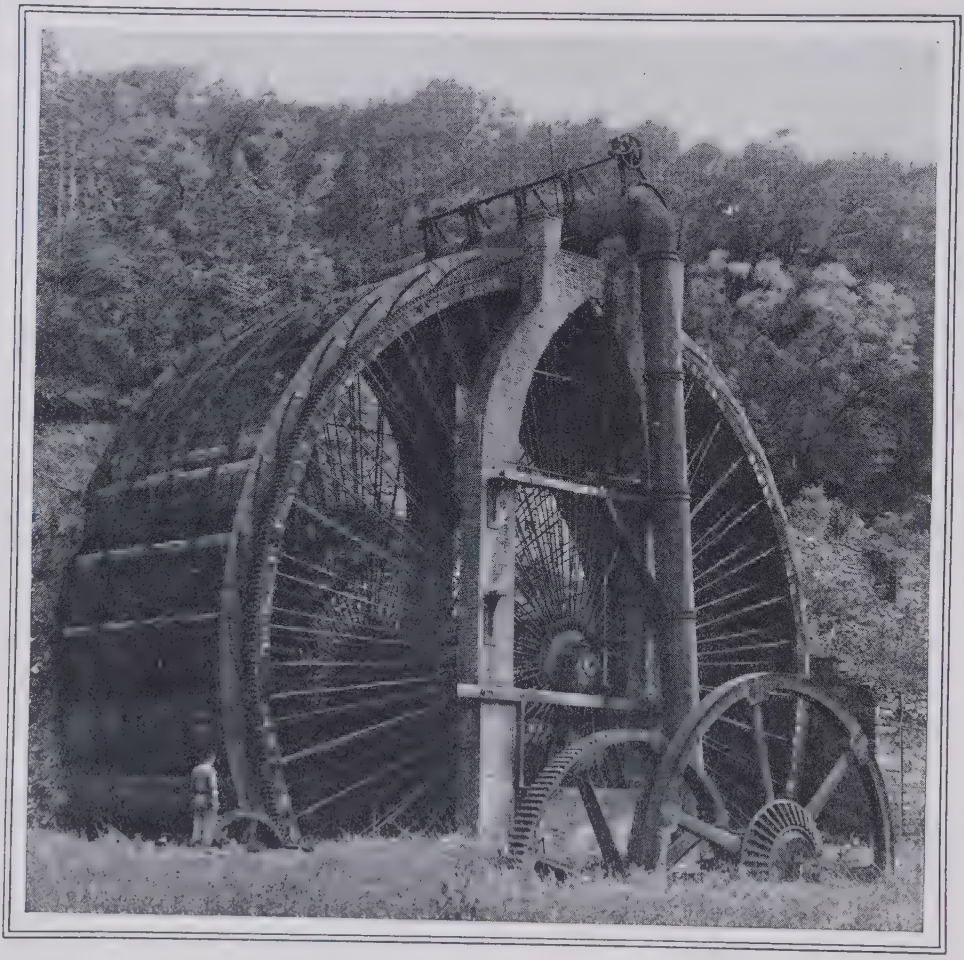
Left to right: Engineers McPhael, McCarthy and Smith; A. Monro Grier, William B. Rankine, and Edward Dean Adams



Map Showing Location of Canadian Power-house

WATER-WHEELS AND TURBINES

Chapter XIX



The "Niagara of Water-wheels"
of the Burden Iron Works
on Wynants Kill, Near Troy, New York
278 Horse-power
Efficiency 84.25 Per Cent

WATER-WHEELS AND TURBINES

CHAPTER XIX

Beautiful as that wonderful work of nature (Niagara) is, it would be more beautiful still if those waters fell upon turbine wheels every one of which was turning the wheels of industry.—Lord Kelvin, New York, 1902

PRELIMINARY PLANS

THE abandonment of the Evershed plan that proposed twelve inlet-canals supplying water to wheels in over 200 wheel-pits, each driving its own mill, by old time methods and the change to a central power producing station requiring some system of power transmission, marked a gigantic innovation in the development and distribution of hydraulic power.

This historic revolution in applied mechanics was introduced by the adoption of the following policy by The Cataract Construction Company, resulting from the survey in Europe by its president in the winter and spring of 1890.

First: To proceed at once under the guidance of its own engineers, with the construction of the hydraulic system to include a short power inlet-canal and a comparatively short tunnel[1] outlet, with a central station for power development and distribution.

Second: To provide for the development of hydraulic power in units of 5000 horse-power, to be operated at a speed of 300[2] revolutions per minute and to be connected with either air compressors or electric generators or both; the turbines to be ordered after the contracts for the tunnel and inlet construction had been let.

Third: To permit such delay in completing the plant as might be found necessary in the effort to secure the most efficient system of power transmission upon the principle that a present sacrifice of time would be wiser than a serious financial risk through premature action.

Fourth: To continue the study of electrical and other methods of power production and distribution, while the hydraulic system was in process of development and construction, it being estimated that about two years[3] would be required to prepare for and install the first turbines.

The turbines proposed far exceeded in power and speed and head of water any then in existence. Furthermore, the speed must be suited for the air compressors or electric generators to be operated. The speed was adopted only after positive assurances from electrical engineers and manufacturers that the design of the generator could conform to that of the turbine, so that the two could constitute, as proposed, a single mechanical unit.

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[1] 1.3 miles instead of 2.5 miles previously proposed.

[2] Later reduced to 250.

[3] Tunnel commenced October 4, 1890; completed December 20, 1892.

In advance of the design of the hydraulic unit it was essential to know the weight of the rotating part of the generator in order to provide for the support of the shaft and its burdens and to so design the governor as to secure the best possible speed regulation with changing loads.

All these problems were without precedent; they involved other and unexpected questions that could be determined only by experiment, under scientific supervision and after the manufacturers had made their own tests and were prepared to guarantee the efficiency and safety of their product and the right to its use.

HISTORY

The situation will be better appreciated if one reviews the early history of water-power, in general, at Niagara Falls and examines the state of the art prior to the year 1890.

The early use of water-power in the United States was for supplying food, clothing and shelter, in grinding grain, weaving cloth and sawing lumber.

The utilization of the falling water for power purposes was by wooden wheels. These could hardly be called of scientific construction; they were of small size, in various forms and under different names and were first used in the grist-mill (that ground grain) and were carried westward in the tide of emigration.

These wheels were popularly known as breast wheels, overshot and undershot wheels, tub wheels and various modifications bearing different names given them by their inventors or makers.

Overshot and breast wheels were applicable where the waterfall ranged from about 10 to 70 feet and seldom produced more than one or two hundred horse-power. Tub wheels of 10 feet diameter, overshot wheels of 20 feet and undershot wheels of 12 feet were in operation.

The most powerful high breast water-wheels ever constructed in England were probably those of 50 feet diameter, 12 feet wide, 15-inch shroud and 120 buckets, of which two wheels, a pair, were erected under a head of 48 feet by Sir W. Fairbairn in 1825 at Catrine, in Ayrshire. They revolved at the rate of $1\frac{1}{2}$ revolutions per minute on journals of 14 inches.

The water was brought from reservoirs covering 120 Scotch acres (48 Scotch acres equal 61 English acres) of an average depth of 8 or 10 feet, through a tunnel 10 feet in diameter and an arched conduit 12 feet wide and 5 feet deep.

When working at full power, these wheels required 98 tons each of water per minute, under a fall of 48 feet, to produce 125 horse-power each.

These wheels were reported a few years since, as operating as well as ever. Overshot wheels of somewhat greater diameter were reported to have been working in England but they were of less width and capacity.

The "Niagara of Water-wheels"[1] or the greatest in America, as it was popularly known, was designed and constructed by Henry Burden on the bank of the Hudson River near Troy, New York, as power for the Troy Iron and Nail Factory, subsequently entitled Henry Burden and Sons. The waterfall was derived from Wynants Kill, a small stream flowing into the Hudson River and regulated by the flow from four lakes in the hills above to give an available head of about 70 feet. The construction of this overshot wheel was commenced in 1843. The wheel was rebuilt in 1851, and was operated regularly for a period of forty-five years, until it fell into disuse by the removal of the works. In 1914 it gave evidence of decay, and ten years later was rapidly deteriorating—an interesting relic of early pioneering in hydraulic engineering and industry.

In 1892, a 500 horse-power turbine of the Jonval type was especially designed for the Burden Works by E. C. Geyelin, engineer of R. D. Wood & Company, of Camden, New Jersey, which firm constructed the turbine and guaranteed an efficiency of 83 per cent. This turbine was to replace the power of the "Niagara of Water-wheels," when the Burden Works were removed to another locality.

Other wheels of the wooden type, of even earlier dates, are still in operation in various parts of the country and are objects of curiosity. An old resident of Niagara has recently referred to a wooden turbine, but none have been found in recent inquiries, unless a wooden "tub" wheel was the wheel referred to.

Metals, such as iron, bronze and steel, soon replaced wood in the construction of water-wheels, particularly when intended for use under high head and a large volume of water.

EUROPEAN TURBINES AND DESIGNERS

Turbine or reaction water-wheel had been known in Europe for a long time.

In 1754 Euler invented the parallel turbine, of which he gave out the theory of operation in 1767.

Fourneyron, of France, made the first commercial turbine. He called it a "Roue a pression universelle et continue."[2]

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[1] This wheel had a diameter of 60 feet and a breast of 20 feet, was built of wood and iron, and was estimated to weigh about 250 tons when soaked. It revolved at a speed of 2½ revolutions per minute, that was maintained constantly by a man at the hand-wheel in control of the amount of water on the power-wheel. Its effective power was calculated at 278 horse-power.

[2] Universal and continuous pressure wheel.

The Fourneyron outward-discharge turbines were in successful operation under high heads in France in 1827. About 1840 the use of reaction water-wheels, having a vertical axis, then extensively employed in France and somewhat in its neighboring countries, commenced to attract the attention of engineers and millwrights in the United States.

Col. Gustave Louis Naville
1848–1926
Chairman, Board of Directors, Escher, Wyss & Company, Zurich; Past-president of Swiss Society of Engineers and Architects; President of Aluminum Industry, Limited, of Newhausen; Colonel of Engineering Corps of Swiss Army

The water-motor was introduced into the United States from France and called the "turbine" and assumed importance less than a century ago. It is now termed the hydraulic turbine to distinguish it from the steam-turbine of comparatively recent origin.

The Jonval axial-flow turbines were improved and manufactured largely by André Koechlin & Cie., of Mulhausen, Alsace, who had distributed more than 400 of these turbines prior to 1848, when one of their engineers came to this country and introduced his Geyelin type.

The Jonval turbine was considered favorably for low heads and was often used with a draft tube which, surrounding the wheel, extended below it and increased its efficiency by adding to its wheel head of water the suction head of the discharge.

Escher, Wyss & Company,[1] of Zurich, Switzerland, were also active at that period, 1850–1880, in the manufacture of a similar type of axial-flow turbine. This firm probably represented the most extended experience of all designers of turbine wheels, having at about May, 1892, constructed 2100 turbines of a total capacity of 136,000 horse-power. Later they produced what was then termed the Francis type, from which they designed the entire installation of the Power-house Number Two and the first five units of the Canadian power-house of The Niagara Falls Power Company.

AMERICAN TURBINES AND DESIGNERS

In 1841, James B. Francis,[2] who was the chief engineer and manager of the entire water-power system at Lowell, Massachusetts, and an eminent authority on hydraulics, stated in connection with improvements in the hydraulic canal system at Lowell, that "the water-wheels of the best patterns of the times and giving a large percentage of effect on the single fall, were becoming old and worn and not adapted to the change expected to be made in the canal." He therefore gave much attention to the development of the new reaction turbine, visiting Europe for a close examination of the state of the art there at that time.

Uriah A. Boyden, of Massachusetts, was soon recognized as one of the most successful designers of turbines, in which he was said to have been assisted by Francis. Boyden devised numerous improvements of importance in the operation and test of turbines, one of which was a successful method of suspending the turbine from the top of its vertical shaft instead of running it on a step at the bottom.

In 1844, Boyden constructed what is called his first turbine; this proved successful and led to many other turbines with similar results.

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[1] Escher, Wyss & Company have built about 7700 water turbines to date (1927), all types aggregating over 6,000,000 horse-power. This grand total is equal to some estimates of the total available horse-power of the entire Niagara Falls.

[2] Born in England in 1815 and died in 1892 at Lowell, Massachusetts.

In 1848, upon the recommendation of Francis, the manufacturing companies of Lowell purchased from Boyden his turbine design and the right to use all his improvements relating to turbines and other hydraulic motors.

Four turbines of the Francis-Boyden type of similar design and dimensions were constructed for two of the Lowell manufactories and completed in 1851. One of these turbines, at the Tremont Mills, was tested February, 1851, and gave, in experiment No. 10, the following results, which it is interesting to compare with those attained by the Swiss turbines adopted for the first installation of The Niagara Falls Power Company:

Statistics	Francis Turbine at Tremont Mills 1851	Faesch and Piccard Niagara Turbine Power-house Number One 1892
Fall of water acting upon the wheel, in feet.	12.8	135.
Diameter of crown of turbine, in feet.	8.33	6.25
Diameter of vertical shaft, in inches.	8.	38.[1]
Revolutions of wheel per minute.	71	250
Effective horse-power.	210	5,000

In 1858, A. M. Swain, of Lowell, Massachusetts, appeared as a turbine designer, and a 72-inch wheel was tested by Francis that showed an efficiency of about 84 per cent. The Swain design exerted an important influence in the development of the highest type of American turbine.

The wheels just described were scientifically designed, and their makers with a few others, under the leadership of James B. Francis, then, 1880, recognized as the foremost hydraulic expert of the country, took pride in their construction and established a well-deserved reputation for American wheels at home and abroad.

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[1] Tubular shaft and solid shaft 11 inches diameter.

Some of the earliest applications of water-power to general manufacturing in important amounts were the following:

Year	Locality	River	Utilized Head in Feet	Total Horse-power
1791	Paterson, N. J.	Passaic	70	4,500
1822	Lowell, Mass.	Merrimac	35	10,000
1825	Cohoes, N. Y.	Mohawk	105	14,000
1835	Manchester, N. H.	Merrimac	52	10,000
1845	Holyoke, Mass.	Connecticut	50	17,000
1845	Lewiston, Maine	Androscoggin	50	11,000
1850	Birmingham, Conn.	Housatonic	22	2,000
1858	Passaic, N. J.	Passaic	22	9,000
1866	Turners Falls, Mass.	Connecticut	35	10,000

In the presidential address at the annual convention of the American Society of Civil Engineers at Montreal, June 15, 1881, President James B. Francis stated:

> Great improvements in reaction water-wheels have been made in the United States within the last forty years. In the year 1844 the late Uriah Atherton Boyden, a civil engineer of Massachusetts, commenced the design and construction of Fourneyron (French) turbines, in which he introduced various improvements and a general perfection of form and workmanship, which enabled a larger percentage of the theoretical power of the water to be utilized than had been previously attained. The great results obtained by Boyden with water-wheels made in his perfect manner, and, in some instances almost regardless of cost, undoubtedly stimulated others to attempt to approximate to these results at less cost, and there are now many forms of wheel of low cost, giving fully double the power, with the same consumption of water, that was obtained from most of the oldest forms of wheels of the same class.

The Francis type of turbine was the first scientifically designed turbine made in this country to any considerable extent, although numerous variations were made in the design by other American makers. Hundreds of patents were issued by the United States Patent Office for new models and for so-called improvements upon the turbine wheel.

Between 1847 and 1900, there were placed upon the market more than sixty varieties of American[1] water-wheels of different characteristics and name or trade titles that had been designed or manufactured by about twenty

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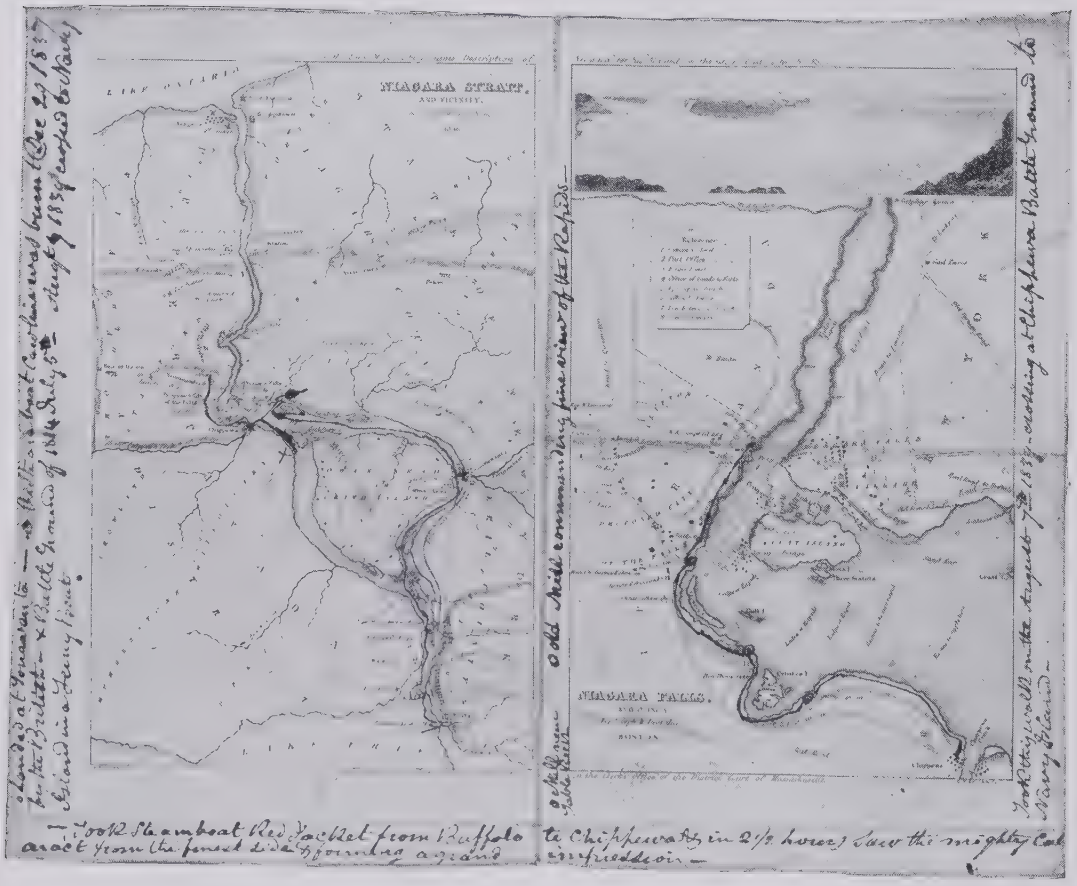
[1] Transactions American Society Civil Engineers. Vol. LXXXV, p. 1237 (1922).

Ingraham Map of 1836

NIAGARA STRAIT *and* NIAGARA FALLS



o Landed at Tonawanta — ◆ Where steamboat Caroline was burnt Dec 29 1837 by the British — × Battle Ground of 1814 July 5th — Augt 9 1839 crossed to Navy Island in a Ferry Boat.

o Mill near Table Rock

o Old Mill commanding fine view of the Rapids —

Took this walk on the August 7th 1839 — crossing at Chippewa Battle Ground to Navy Island —

— Took Steamboat Red Jacket from Buffalo to Chippewa & in 2½ hours saw the mighty Cataract from the finest side forming a grand impression —

Reduction from Ingraham's Map in His Manual for the Use of Visitors to the Falls, Boston, 1836 separate companies. Nearly all of these were less than 100 horse-power, and designed for use under low heads of water. These wheels were generally made to standard or trade sizes that were kept in stock ready for immediate delivery, with a guarantee of patent protection and of an efficiency of 75 per cent under a head of water not exceeding 100 feet. Above that head the reaction turbine was not considered as efficient as impulse or jet wheels, such as that known as the Pelton wheel, that was recommended for such heads.

WATER-WHEELS AT NIAGARA

The first known use of the water of Niagara for power purposes was by a Frenchman, Chabert Joncaire, Jr., in or about the year 1757. He built a small canal on the river bank, taking and discharging its water above the falls. It is believed that he used a wooden overshot wheel under a head of about 6 feet. John Steadman, a settler of about 1760, repaired and used the sawmill operated by this power.

A project or tentative effort to utilize the waters of Niagara in the earliest attempts was that represented by a woodcut illustration of a publication in which the whirlpool of Niagara River was shown with a small stream falling from the top of the cliff upon an overshot water-wheel that discharged its waters into the whirlpool chasm below, to operate an inclined railroad between the Whirlpool Rapids and the top of the bluff on the Canadian side.

In 1807 Augustus Porter built a grist-mill, with two run[1] of millstones, on the site of the original French sawmill, on the loop canal and used a separate water intake probably with a breast or overshot wooden wheel. The map of 1836 by J. W. Ingraham, of Boston, on page 92, indicates the location of this mill.

In the period of awaiting new leaders with capital for the completion of the development projects, the population at Niagara Falls increased but little. There were a number of mills built that obtained their power at low heads from the upper and lower loop canals upon the bank of the river above the falls, and from the branch of the upper rapids that ran between Goat and Bath islands on the river edge. Wooden wheels of the several varieties applicable to such conditions were used. Millstones to the extent of twenty-six runs, or pairs, were in operation on the raceways before that property was acquired by the state. The total utilized power of the lower raceway was estimated at 400 horse-power.

The height of the falls at Niagara, and the enormous quantity of water to be controlled and utilized, were soon recognized as requiring—as in clothing for the unusual person—custom-made and not ready-made products.

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[1] See Appendix H, Volume II.

From the variety of hydraulic motors mentioned as having been in use at Niagara Falls, it seems that manufacturers found the locality an excellent place to advertise their products. The name of the location connoted water-power and naturally a familiarity with water-wheels. Moreover, the multitude of visitors would naturally inquire, if at all interested in the subject, as to the type of wheel or turbine in use there, and what preferences were given by the local manufacturers to the new designs placed upon the market. Some of the trade names for American water-wheels or turbines were the following, that indicate the tendency of manufacturers, at that time, to utilize higher heads than 100 feet, and the effort of wheel makers to attract attention to their provisions therefore: viz., Hercules, Samson, Victor High Pressure, High Head, High Duty Standard, Special High Head, Special High Duty, etc., but no Niagara. The fancy names commenced to appear in the seventies, replacing the names of old and well-established firms that had valuable reputations to maintain by scientific designs for special requirements, while quantity production of standard or popular sizes, "protected" by patents, and illustrated by tables of performances, was advocated as a new and expanding American industry.

There were other types of wooden wheels in addition to those already mentioned as in use at Niagara. The tub wheel, that was placed in a horizontal position and discharged its water at both ends was often used in sawmills. The scroll wheel had its advocates. The Porter mill used what was then called the "old-fashioned flutter" wheel. All of these wheels were of comparatively small horse-power.

A French turbine of about 20 horse-power, and another turbine that was called the "New American," both of metal, were mentioned as in use. The "Old American" and the "Special American" wheels were also in service.

HIGHER HEADS UTILIZED ON CLIFF

All references hitherto to the uses of Niagara power for manufacturing have been to those plants located either between Goat and Bath islands or on the northern bank on the opposite side of the river, where they derived their power from the low heads prevailing on the two loop canals indicated upon the Emslie map of 1846, shown on page 96.

Although the hydraulic canal was quite incomplete, the river water had been admitted and the high head at its forebay, on the cliff, was available for the development of hydraulic power in 1861.

It is stated that many wooden wheels were broken in Niagara mills at various times in their use under 50-foot heads. To avoid this danger where feasible, it was considered good policy to divide a "head" or fall into several levels of

20 or 25 feet each, at which the use of the water was repeated with several smaller wheels.

As high heads required stronger material in construction, iron plates were used by boiler makers and machine shops, that became busy with this new industry, until millwrights and their mechanical engineers took up the scientific designing of turbines and produced wheels that did not pit, as did their earliest productions, and that rose in efficiency under scientific test, from 75 per cent so readily guaranteed to 86 per cent so seldom attained.

The wheel employed in the first use of the waters of the hydraulic canal in the early seventies was a wooden wheel at the bottom of a 24-foot wheel-pit. It operated a flour mill built in 1874 by Col. Charles B. Gaskill. The wheel-pit was deepened to 40 feet and subsequently to 96 feet, the water being discharged by short tunnels from the face of the cliff to the river below, as will be observed in the view of the cliff industries in this chapter, page 98. At the greater head, a so-called "American" turbine of metal was installed. The picture of a turbine wheel, on page 97, with a crown gear wheel by its side, has been recognized by a former employee as a 25-inch runner that was removed from its pit because "it was worn out." It is stated that the wheel was made of a bronze alloy that wore out quickly, a new wheel being required every three or four years. They seemed, it is said, always to pit[1] in the same place, near the entrance edge of the vanes. Two pit holes and a broken blade may be seen in this picture of the junk heap of the Gaskill mill.

The above sketch of the history of water-motors in the United States, and the condition of their development and use at Niagara in the period of 1880–1890, are intended to indicate the problem of design and designer, presented by the unusual requirements of The Cataract Construction Company, for the development of Niagara power.

When the state acquired the property that now comprises the New York State Reservation, in 1883, it purchased and demolished all the mills located above the falls on the bank of the river and between the islands. The only location thereafter available, with water-power ready for manufacturing, was the canal and its forebay on the top of the bluff beyond the falls or the river bank at the foot of the cliff.

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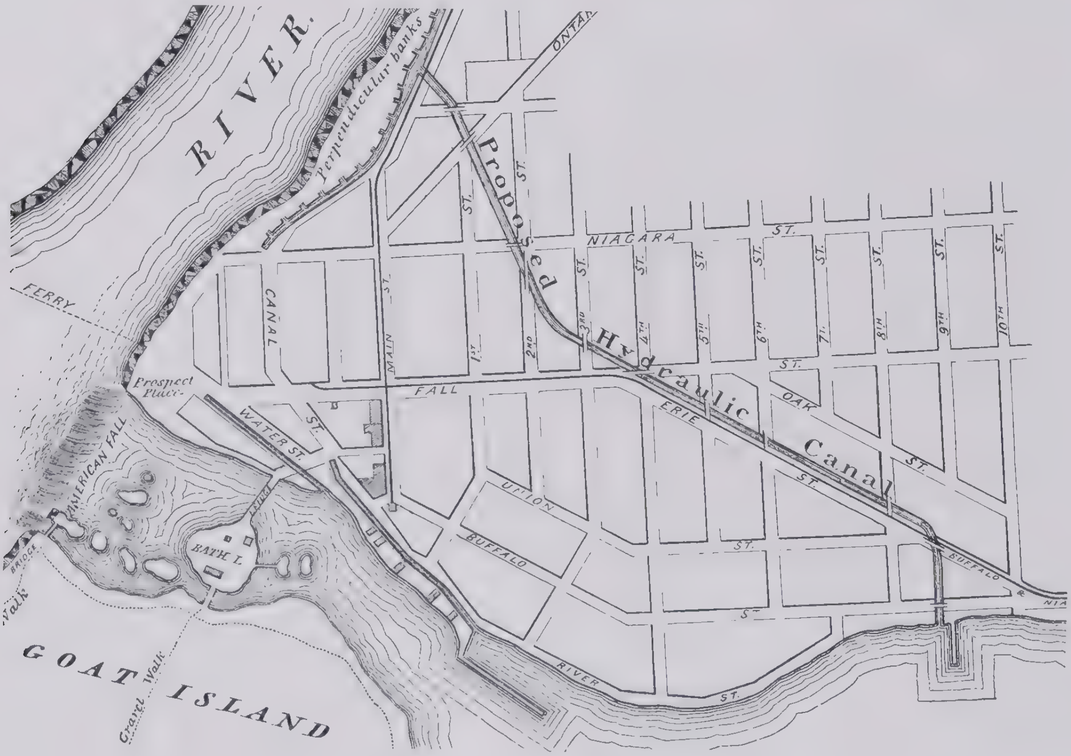
[1] William Monroe White, hydraulic engineer of the Allis-Chalmers Manufacturing Company, expressed his theory regarding the "pitting" of runner vanes in an address about turbines and hydro-electric equipment, before the Boston Society of Civil Engineers, December 19, 1923, as follows:

"The question has never been settled as to just what really causes a runner to pit. My preferred theory is usually referred to as the 'nascent oxygen theory.' By this I mean that when the water passes between the vanes and is discharged from the runner the pressure on the water is suddenly relieved. At the moment of this relief of pressure oxygen separates from the water. When the runner vanes are shaped so that there is a chance for the water to leave the back of the blade the nascent oxygen evidently collects in that space, and eats the material of the runner, producing the pitting referred to. Another theory is that of electrolysis, but that does not fit in very well with the fact that the runner only pits in places where a vacuum or pocket can occur."

Immediately after the purchase of the hydraulic canal property, including Port Day, the forebay and lands, by the Schoellkopf and Mathews interests, the hydraulic works were carried forward to completion, and a flouring mill was erected having a capacity of 1200 barrels of flour a day, that was operated by cast-iron wheels of a total of 900 horse-power from a 50-foot head of water.



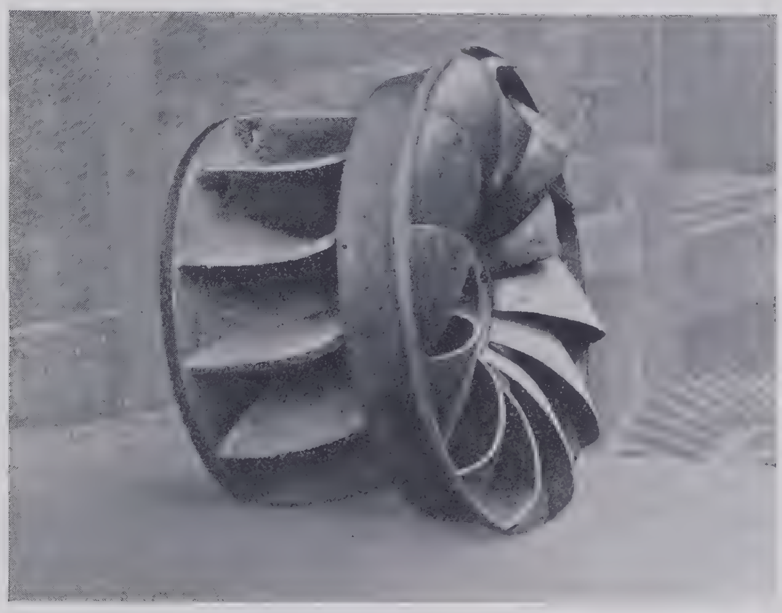
Niagara Falls Village
Showing Proposed Hydraulic Canal
Submitted by P. Emslie, December, 1846

Another flouring mill soon followed, in the same interests, using the water under an 80-foot head. A pulp mill was also constructed in 1892 using the water a second time under a head of 125 feet.

Other industries availed of the water from the canal, and some organizations later found locations for their factories below the cliff on the river bank, bringing the water required for power from the forebay of the canal, over the bank and down the cliff in pipes, where the iron turbines of 1880–1892 were advantageously employed.

The difference of head utilized, and the variations in the depth of wheel-pits and discharge outlets, are easily recognized in the reproduction of the side of the cliff (page 98) with its evidence of industrial activity and hydraulic waste.

The first use of the total head available between the falls and the cliff was that made by The Niagara Falls Hydraulic Power and Manufacturing Company in December, 1896, with turbines constructed by the James Leffel Company of Springfield, Ohio, of 6850 total horse-power derived from three wheels of 1650 horse-power and one wheel of 1900 horse-power, all operating under a fall of 212 feet, at 250 revolutions per minute, with water from the Schoellkopf (hydraulic) canal.



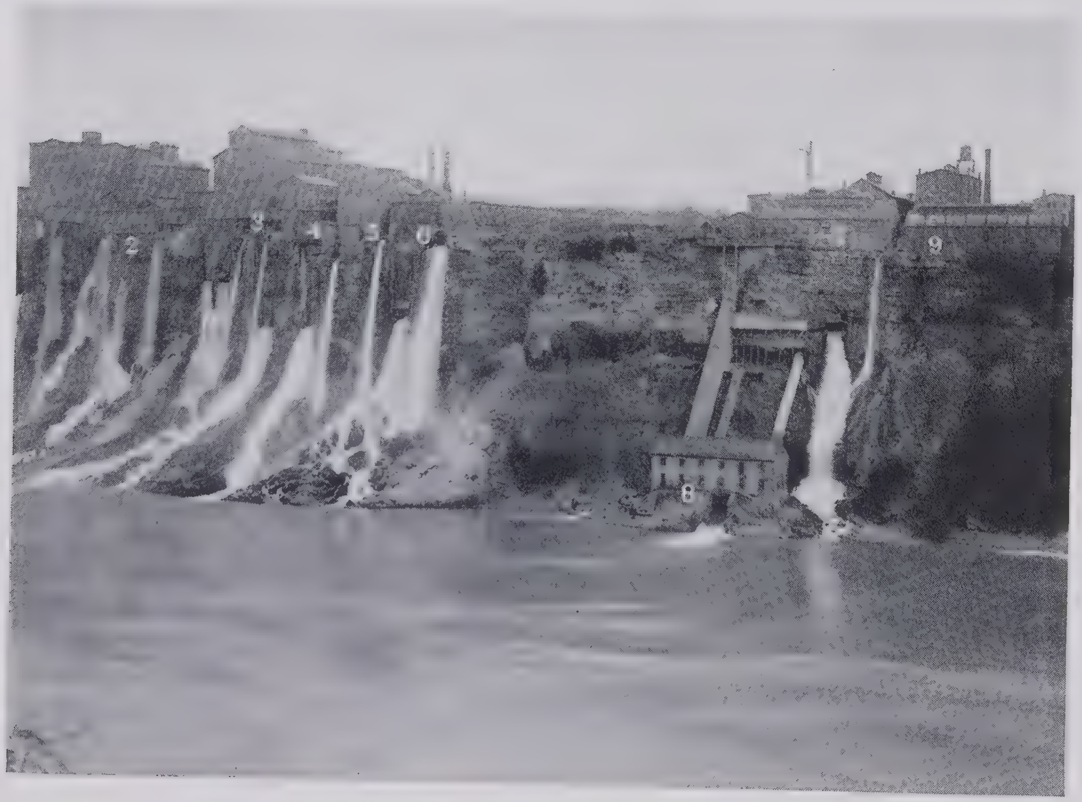
TURBINE RUNNER OF EARLY GASKILL MILL

These wheels drove dynamos that supplied direct-current electricity for street cars and arc lamps and for other power purposes in the village of Niagara Falls.

The Power-house Number One of The Niagara Falls Power Company was operating its hydro-electric unit of 5000 horse-power in the spring of 1895 and delivering its alternating current to its power customers in the summer of that same year, using the maximum hydraulic head available by its inlet-canal, wheel-pit and tunnel from its power-house on the river bank above the falls.

TURBINE PROJECTS SUBMITTED TO THE INTERNATIONAL NIAGARA COMMISSION

In the spring of 1891, upon the return from abroad of the several officers and engineers of The Cataract Construction Company and the receipt of the formal report of April 13, 1891, of the International Niagara Commission, the board of engineers of the cataract company engaged in the intensive study of the work of the commission and the results of the foreign investigations.



Milling District, 1893, Showing Partial Use of Water

1 *Central Milling Company*
2 *Niagara Wood Paper Company*
3 *Schoellkopf & Mathews Flour Mill*
4 *Pettebone Pulp Mill*
5 *Charles B. Gaskill Flouring Mill*
6 *Niagara Falls City Water Works.*
7 *Cliff Paper Company (first use of water, 75 ft. head)*
8 *Cliff Paper Company, Lower Mill (second use of water, 125 ft. head)*
9 *Oneida Community Mill*

Of the seventeen projects submitted to the commission, fifteen were European and five American. The latter included a hydraulic project by the Pelton Water Wheel Company, of San Francisco, California, and a compressed air project from the Norwalk Iron Works, of South Norwalk, Connecticut. Both of these projects represented combinations for transmission of power, the Pelton wheels driving high-pressure pumps, air compressors and dynamos; the Norwalk compressors were to be driven also by Pelton wheels. These latter competitors assumed in their memoirs, presented to the commission, that the head at Niagara was too great for pressure turbines and therefore the Pelton type of wheel was proposed. Prizes and premiums for combined projects were awarded to each of these competitors.

The three other American projects, one electric and two hydraulic, were not considered in the award of prizes because they did not conform to the terms of the letter of invitation of The Cataract Construction Company.

In the distribution of awards for combined projects, the highest went to manufacturers in

Zurich, for hydraulic and pneumatic projects, and
Geneva, for hydraulic and electric projects.

The highest prizes and premiums awarded for hydraulic development were made for projects submitted by

Escher, Wyss & Company, Zurich,
Ganz & Company, Budapest, and
Faesch and Piccard, Geneva, for their turbine part in a combined hydro-electric project.

A detailed description of these turbine projects will be found in Chapter X, Volume One, also in the Appendix E, same volume.

CONSULTING ENGINEERS

In the autumn of 1892, when decisions were pending of vital importance to the Niagara enterprise, it was deemed a wise policy, by its management, to secure the guidance of those engineers who, by education, experience and position, were best qualified to advise regarding the engineering problems particularly involved in the questions of hydraulic and electrical systems to be adopted.

The International Niagara Commission had indicated clearly the state of the art of power transmission in the year 1891, and had facilitated acquaintance with European designers and constructors, of which The Cataract Construction Company might wish to avail, and which could be effectively done by the selection of advisory engineers as resident representatives abroad. The conferences of the commission had brought before each of its members, not only all the memoirs and plans submitted by the competitors for the prizes and bonuses offered, but also the engineers and designers themselves, who by their personal explanations and suggestions had particularly qualified the members of the commission to advise the Niagara company at that period of its development. Appreciation of this fact led The Cataract Construction Company to secure, at various periods, the services of three of the five members of the commission, and one of the competitors, as consulting engineers.

The hydraulic and mechanical were the first branches of engineering to be considered in formulating plans for machine design and construction, and these were soon followed by the electrical branch, when it was decided to coordinate the three sciences in the design of a single unit machine for power development and distribution.

The principal advisers in the negotiations that resulted in a contract for turbines with Faesch and Piccard, of Geneva, in 1892, were the following members of the International Niagara Commission, all of whom served during its entire existence, and remained as advisers in the Niagara engineering problems until the major questions were determined:

Dr. Coleman Sellers, of Philadelphia, Chief Engineer.

Col. Theodore Turrettini, of Geneva, Switzerland, Foreign Consulting Engineer.

Prof. W. Cawthorne Unwin, of London, England, Consulting Engineer.

FOREIGN ENGINEERS INVITED TO SUBMIT TURBINE PROJECTS

Familiarity with the turbine designers and constructors of the United States, by investigations prior to the sessions of the International Niagara Commission in London, made evident to the board of engineers of the cataract company, in review of the domestic and foreign conditions of the turbine industry, that no American experience could be depended upon to design turbine units to develop 5000 horse-power, on vertical shafts running at 250 revolutions, under a 140-foot head of water and to support electrical machines of similar power as an integral part of a single machine unit. On the other hand, personal inspections abroad gave confidence that the requirements at Niagara as then understood, could be promptly met by foreign experience and responsibility of undoubted character and value.

It was therefore determined to select several of the hydraulic competitors that had been approved by the International Niagara Commission and invite them to submit plans for the turbine installation at Niagara, with the requirements of which such competitors were already somewhat familiar, having studied the details for their projects that had won prizes and premiums from the commission.

SERVICE OF COLONEL TURRETTINI

In anticipation of seeking the co-operation of engineering organizations in Switzerland and its neighboring countries, in formulating the definitive plans for the development and distribution of Niagara power, negotiations were opened within sixty days after the close of sessions of the International Niagara Commission, for the services of Col. Theodore Turrettini, of Geneva, as foreign consulting engineer of The Cataract Construction Company.

Col. Theodore Turrettini
1845–1916
Engineer Director of Geneva in Its Utilization
of Water-power of the Rhone, Regulation of
the Level of Lake Leman, Construction
of the Power-house of Chevres
1890–1899
President Conseil-administatif of Geneva, Seven
Years as Consulting Engineer for Niagara
Interests. Visited the Falls in
1891, 1893, 1899
"Décidément l'Amerique est le pays de l'avenir"

This appointment was formally made March 10, 1891, under the terms of the letter[1] of appointment of that date. The public announcement thereof in the foreign press was authorized.

Colonel Turrettini made three visits to Niagara, in 1891, 1893 and 1899.

His services as a member of the company's board of engineers, in the formative period of plan and construction, were much valued, as well as his helpful suggestions and counsel by correspondence, and his personal representation of the company's interests in Europe, in contract negotiations and investigations.

He came to New York early in May, 1891, and remained about six weeks, in conferences with the board of engineers at Niagara, and with the officers of the company, who accompanied him in visiting various power-plants, electrical establishments and other manufactories, to familiarize himself with such industries and their methods of operation.

In the consideration of the probable cost of foreign machines at Niagara, it appeared doubtful if even the comparatively lower cost of foreign skilled labor would offset the expense of transportation and much less the customs duties. It was therefore decided, in contracting for turbines or generators abroad, to reserve the privilege, in event of need, to purchase the approved designs and working drawings for the construction of these machines in America, under the personal supervision of the designers, during both construction and installation.

Soon after the return of Colonel Turrettini to Geneva, he visited several of the Swiss turbine manufacturers and invited them to submit their *avant-projet* for Niagara turbines, with an estimate of the cost of execution in their own shops and an estimate of their charges for working drawings and for the cost of supervision of the construction in the United States for account of the cataract company, also for their guarantee of efficiency and good working.

OFFICIAL REPORT OF TESTS OF LAUFFEN-FRANKFORT LINE

Although the officials of the cataract company were informed that the operation of the Lauffen-Frankfort line of power transmission was successful, by Colonel Turrettini, who attended the tests late in September, yet the final and official tests for record had been entrusted, after the close of the Frankfort Exhibition, to a special commission under Professor Weber, of the Zurich Polytechnikum, who was empowered to make a complete series of experiments to ascertain exactly the efficiency of the installation running at full power and under such conditions as he thought best.

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[1] See Appendix L, Volume II.

It was stated that the choice of Professor Weber gave the assurance that these trials would be made in the most conscientious and competent manner, to facilitate which special measuring instruments were prepared.

As the revolutions of the Niagara turbine, and the weight to be sustained and governed, could only be determined after conference with the electrical engineers who were to design alternators for the same shaft as that of the turbine, no definite contract for either hydraulic or electrical machines could prudently be made until the official report of the Lauffen-Frankfort transmission had been made and analyzed.

Professor Weber informed Colonel Turrettini in January, 1892, that the results were very good.

The detailed report, made public later by the committee of the Frankfort Commission, showed a total net efficiency from alternator to motor of 77 per cent.

Colonel Turrettini pronounced the operation very satisfactory, and that this transmission of 175 kilometers justified the cataract company in anticipating its proposed power transmission, 32 kilometers to Buffalo, as an assured success.

The cataract company first adopted, tentatively, 2500 horse-power as the power unit of its turbine. Its first invitations for the study of the appropriate designs, or the *avant-projet,* were issued from Geneva, July 11, 1891, by Colonel Turrettini, its foreign consulting engineer, to three Swiss firms that had received from the International Niagara Commission the highest awards or premiums for projects for hydraulic development.

Escher, Wyss & Company, of Zurich, Switzerland

Faesch and Piccard, of Geneva, Switzerland

Joh. J. Rieter & Company, of Winterthur, Switzerland

TURBINE PROJECTS

Escher, Wyss and Company devised a 200 horse-power turbine consisting of two wheels superimposed, that was in operation in a factory in Austria in December, 1891, and gave entire satisfaction, particularly in its great rapidity of rotation, such as would facilitate direct operation with an alternator on a single shaft. This turbine was experimental in character in anticipation of the use of its type in their proposed design for Niagara.

On January 20, 1892, this firm presented a Niagara project of this type, of 5000 horse-power. The mean diameter of the two wheels corresponded to the normal speed of 300 revolutions, but the upper wheel had a crown slightly larger in diameter than the lower one. The difference in the surface of the turbines was calculated according to the water pressure and to the weight of the turbine, its shaft and the generator. The upper turbine could thus be used to support partially the revolving mass so as to diminish its weight at the points of contact in operation.

Messrs. Faesch and Piccard also presented, in January, 1892, a somewhat similar project of the same horse-power and revolutions. This turbine also consisted of two superimposed wheels, each with its own independent water-inlet, but the system by which the support of the revolving mass was obtained differed from the other project.

While the lifting, in the Escher-Wyss design, was secured by the difference in the size of the crown of the Jonval inward-discharge turbines, Faesch and Piccard used equal sized Fourneyron outward-discharge turbines. The strain on the blades of the turbines was avoided by the balancing of the water pressure, and the weight of the 76 tons of turbine, shaft and dynamo bore on a solid disc, which replaced the arms of the upper turbine. The hydraulic pressure was produced under this disc by means of apertures in the upper part of the distributor. When the machine was not in motion, its weight rested on a support at the upper end of the shaft.

The regulators or governors, of the two projects differed considerably. The technical construction and operation of the Faesch and Piccard regulator were preferred by the board of engineers of the cataract company.

FAESCH AND PICCARD PLANS AND ESTIMATES

Complete turbine plans were submitted by Faesch and Piccard in March, 1892, and were selected by the board of engineers and the foreign consulting engineers of the cataract company for elaboration and construction. As soon as working drawings could be prepared, they were submitted to the I. P. Morris Company, of Philadelphia, for an estimate of the cost of construction and installation.

With this estimate in hand for comparison with the preliminary estimate of Faesch and Piccard, it was easily shown that it was much cheaper for the cataract company to build the turbines in this country and pay the royalties on the design, the charges for the working drawings and for the guarantee of efficiency, as well as the salary and expenses of the superintendent of construction, than to have the turbines constructed by Faesch and Piccard in Switzerland, with the unavoidable charges for insurance, rail and ocean transportation and customs duties added thereto.

Faesch and Piccard undertook the investigation, for their own guidance, of the cost of transportation of turbines such as they had designed for The

Cataract Construction Company, and the rate of duty thereon to the United States. They also, with the assistance of their representative in the States, ascertained the probable cost of materials and labor to produce a similar turbine in America, and gave the result of their investigation as follows:

> Everything considered, we do not believe that it is possible for us to offer you any advantages in competition with Americans, such as would prompt you to give us the preference. Since, as a result of our investigations and calculations, we shall not be able to maintain the advantages in price which we expected to offer you, we refrain, with regret, from making you any proposal.

TURBINE SPECIFICATIONS

The plan of the single inlet-canal and its power stations, under favorable consideration at that date, provided for two power-houses, one on the westerly side of the inlet-canal for the development of electrical energy, and the other on the easterly side as the compressed-air station. For the electrical station an arrangement was suggested of four turbines of 2500 horse-power each, all in a single group pit of 10,000 horse-power. This was to be studied in comparison with the advantages of operation and costs of placing each turbine of 2500 horse-power in an independent pit by itself.

For the compressed-air station it had been recommended that turbines of 2500 horse-power with vertical axis should be connected by the shaft with two compressors of 1250 horse-power each, all operating in underground chambers.

Proposals from Joh. J. Rieter and Company were received, dated August 29, and October 1, 1891, each for four Girard type turbines at 75 revolutions per minute; one with horizontal and the second with perpendicular shaft directly connected to an air compressor of 1250 horse-power each, in wheel-pit groups of 10,000 horse-power.

The letters of invitation stated that these plans were simply general indications and did not in any way restrict the designers in the preparation of what they considered best adapted for the purposes intended. It was explained that there should be taken into consideration the diminution of the section of the wheel-pit as an important element of economy, and that the excavation of a continuous slot would be more economical than that of independent wheel-pits.

Consideration was requested as to whether the inertia of the turbine would be sufficient to take up any sudden changes in the load, or whether it would be necessary to provide for a supplementary fly-wheel to regulate the working of the compressors.

With the *avant-projet* it was desired that there be submitted estimates of the cost of (1) execution in the shops of the designers; (2) preparation of detailed plans for execution in the United States; (3) supervision of construction; (4) guarantee of efficiency and good work.

"AVANT-PROJET" FOR ELECTRICAL GENERATORS

While negotiating the contract for turbines, preliminary plans for electrical generators of 2500 and 5000 horse-power each were submitted by the Oerlikon Company for consideration.

As the Oerlikon Company was the principal party to the design and execution of the experimental line of transmission of power from Lauffen to Frankfort, and was frequently united with other Swiss concerns when turbines were required to drive the electrical generators of the Oerlikon Company, the engineering studies of Niagara requirements soon developed an agreement as to the units of power, revolution and weights considered most advantageous for the Niagara installation, and led the cataract company to adopt the power unit of 5000 horse-power at 250 revolutions per minute.

The plans for the cataract company in its Niagara power development had reached, by July, 1891, the stage of

1. Hydraulic system of a single inlet-canal, the shortest possible discharge tunnel, and a central station of power development.
2. Local distribution of power by direct current of electricity.
3. Transmission of power to Buffalo by compressed air.

In the early autumn of 1891, it became evident that the alternating current of electricity could be safely and economically controlled for the transmission of power more than five times the distance from Niagara to Buffalo. It was then recognized that in the plans for development and distribution of power at Niagara, all other methods could be disregarded and only electricity employed for both local and distant use. From this period all serious attention was concentrated upon electrical installations, generators, transformers, lines of transmission, motors and power and light distribution.

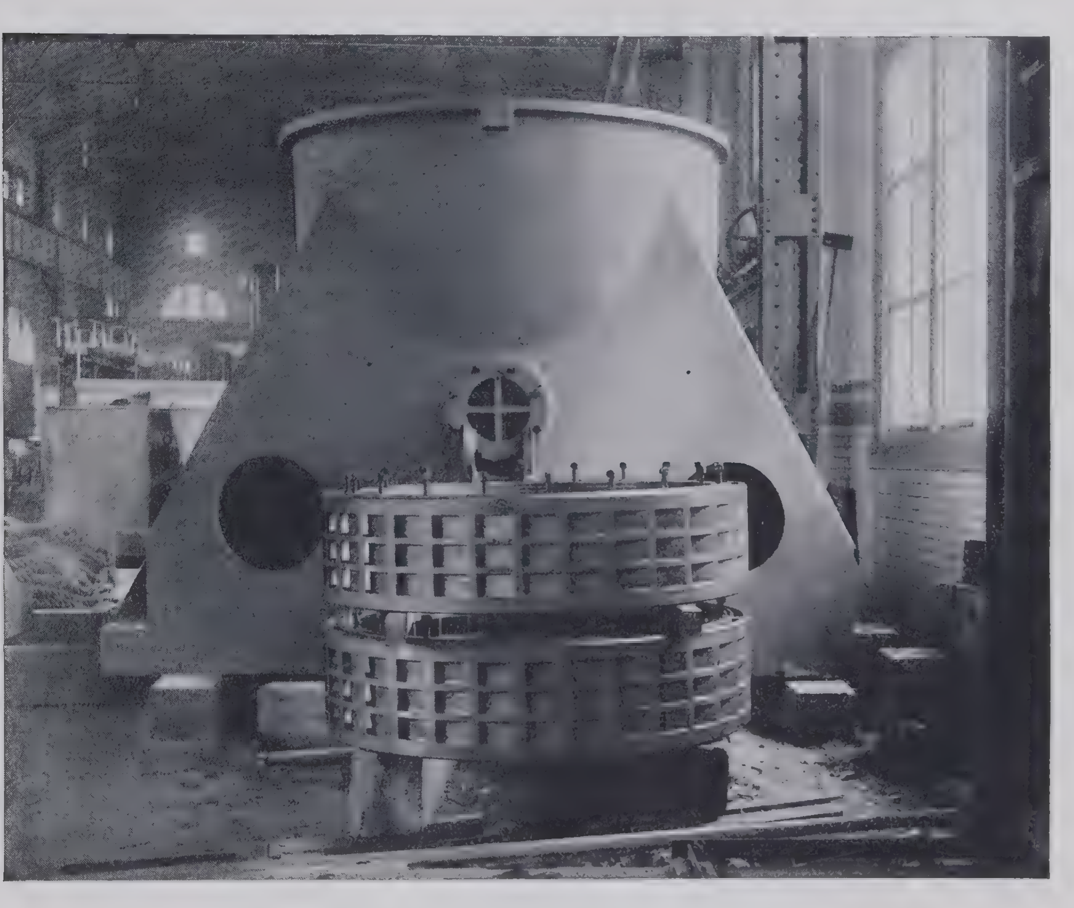
THE TURBINE UNIT

The design of a hydraulic motor of this unprecedented power called not only for greater skill, derived from the sciences of mechanics and hydraulics, but also for the strongest of metals and in quantities that surprised those not familiar with the subject, when they first saw the various elements of the machine assembled and in position for action.

Elements of the double-wheel turbines of Power-house Number One, of The Niagara Falls Power Company, designed by Faesch and Piccard, of

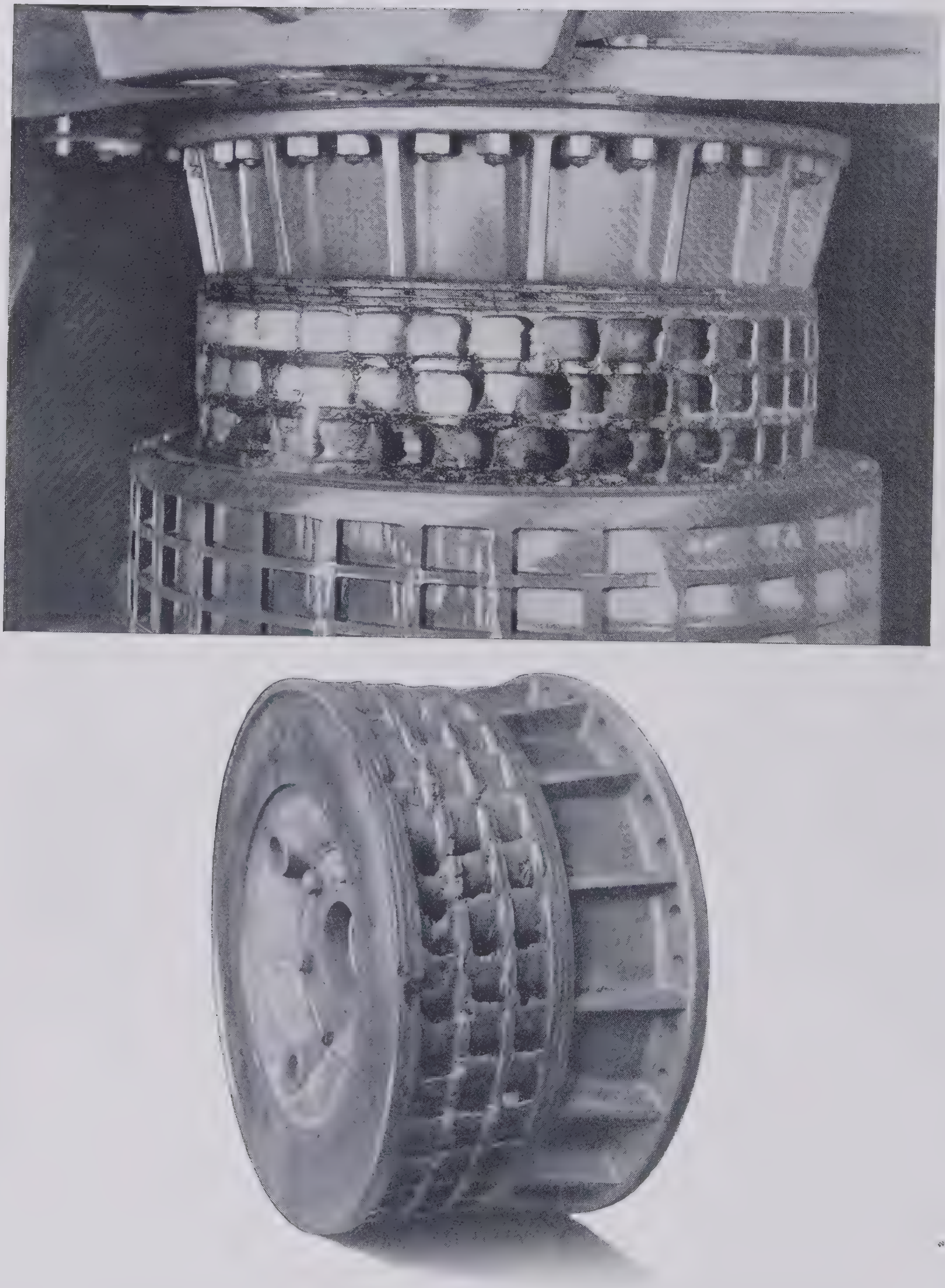
Geneva, Switzerland, and constructed by the I. P. Morris Company, of Philadelphia, are here illustrated. (See also page 118.)

When superimposed in their proper position, the two wheels, the upper one inverted, were 10 feet 10 inches apart from center to center. Each wheel was 16 inches face, made up of three tiers of openings each 3⅝ inches wide, with partitions between them. The water entered the inside of the wheel and developed its power as it forced its way through the discharge openings outward into a case that covered the wheel, from which the water was discharged into the conduits below.



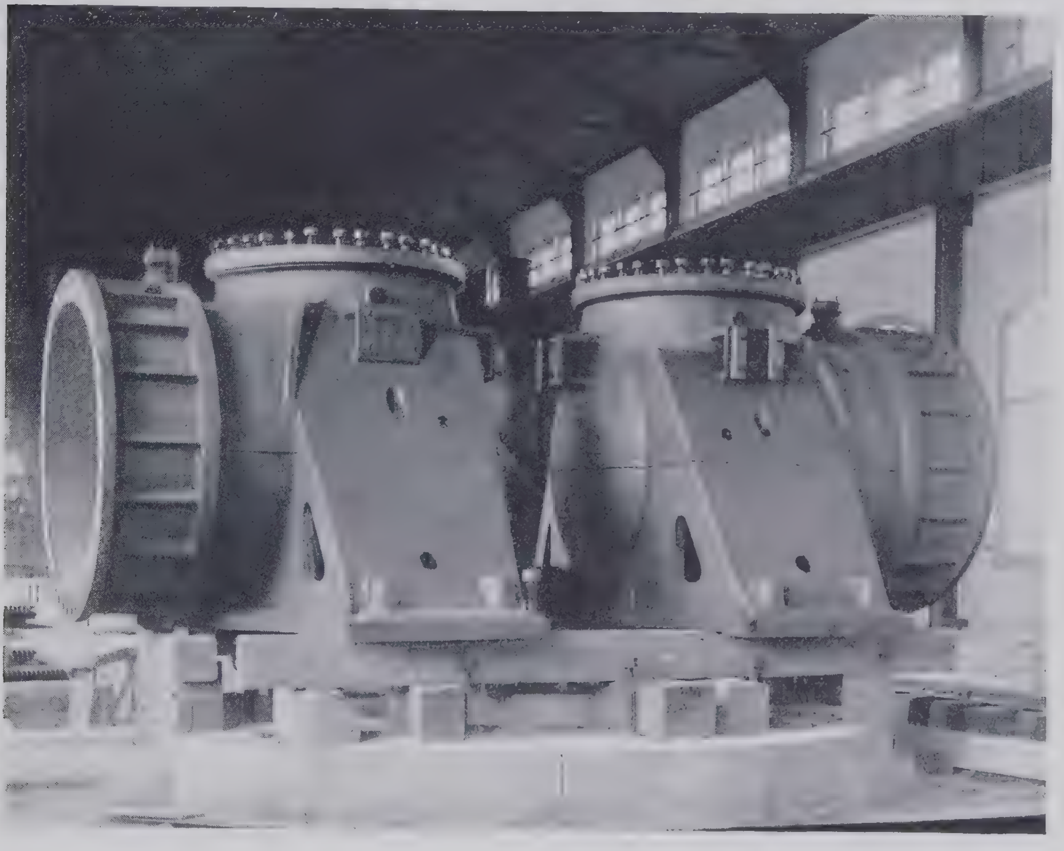
Turbine Runners; Lower Penstock Elbow for Power-house Number One
I. P. Morris Company, Philadelphia, Makers

The control of the speed of revolution of these twin wheels, or turbines, by an automatic governor, is accomplished by the use of circular iron collars, outside



Lower Wheel of the Fourneyron Double Turbine Number Four in Power-house Number One, Worn by Fifteen Years' Service. Replaced in 1904 by Francis Type of the wheels, each collar being wide enough to cover all the openings of each wheel. The collars are connected by rods and so arranged that as they move up or down over the face or side of the wheels, no two levels of discharge are opened or closed at the same time.

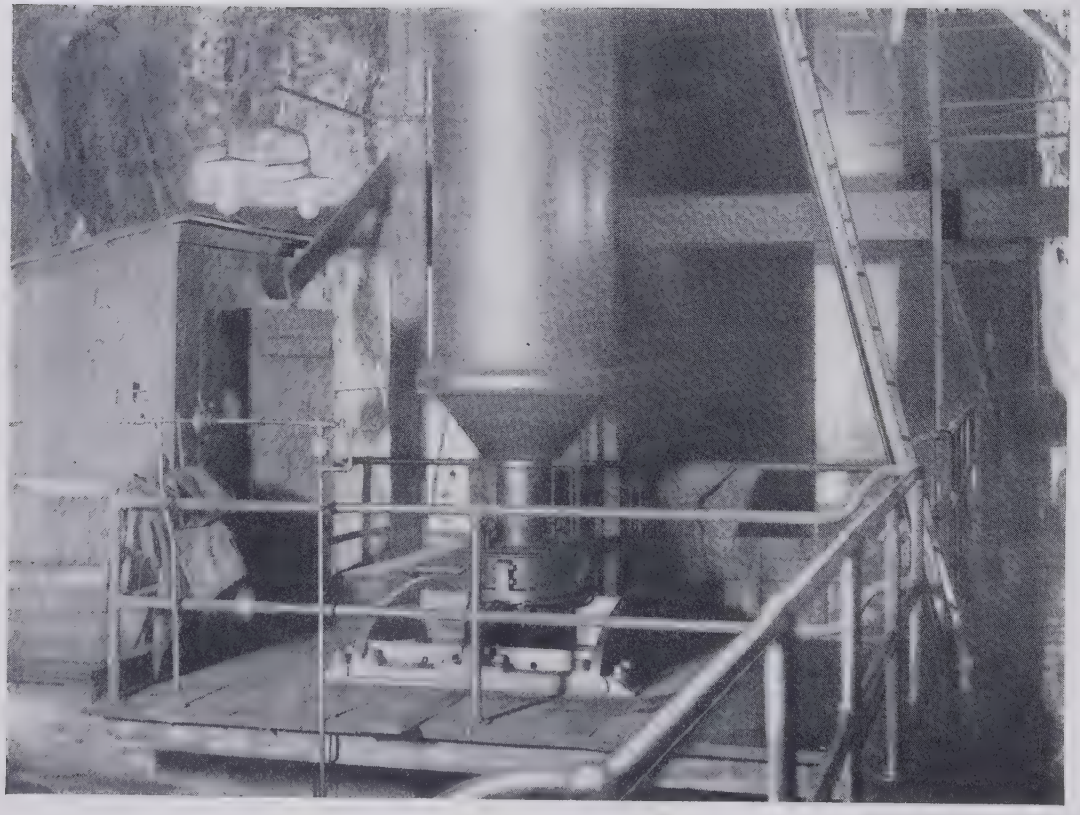
The penstock is in the form of a continuous tube 7 feet 6 inches in diameter, utilizing a head, or fall, of water of about 140 feet.



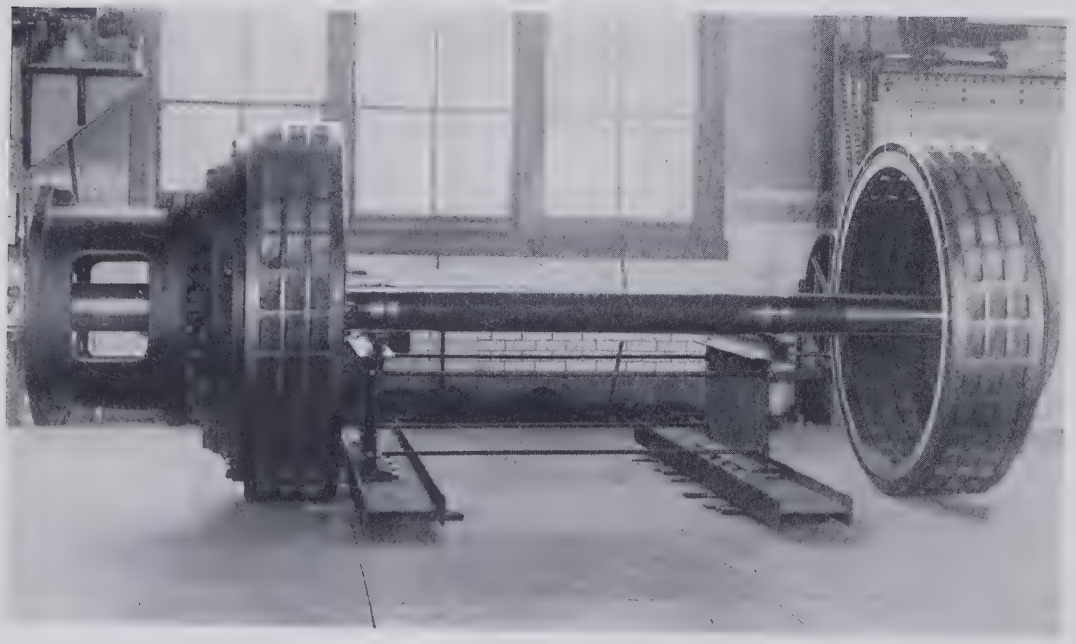
Turbine Wheel-cases for Power-house Number One
I. P. Morris Company, Philadelphia, Makers

THE TURBO-GENERATOR

The single machine, that changes the force of falling water to the power of electric energy, consists of a turbine as the prime mover, mounted upon a vertical shaft which revolves a generator on its top, a total weight of seventy-six tons of metal, turning at the rate of 250 revolutions per minute, the linear velocity of the field ring of the alternator being 105 miles per hour; the elements combined constituting a hydro-electric unit, or turbo-generator, producing



Section of Shaft Connecting Turbine and Generator, Power-house Number One



Turbine Runners in Power-house Number One the equivalent of 5000 horse-power, constantly available, locally or at a distance, within a radius of more than 100 miles.

PROFESSOR PICCARD DESCRIBES THE FAESCH AND PICCARD TURBINE

Prof. Paul Piccard, the designer of the Niagara turbine, describes the machine as follows:

The Cataract Construction Company adopted units of 5000 horse-power at 250 revolutions per minute, the discharge of each turbine being 430 cubic feet per second with an efficiency of at least 75 per cent. The number of revolutions was too great to be obtained with a single turbine wheel, the diameter of the wheel corresponding to this speed being too small to allow the distributor the section necessary to discharge the large quantity of water required. In order to maintain this diameter, it was necessary to adopt a double turbine, or two turbine wheels fixed on the same shaft and each having its own distributor. These are radial outward-flow turbines, like those of the Fourneyron system, and both wheels are alike. The water is introduced upon the whole inner circumference.

Prof. Paul Piccard
of Geneva, Switzerland, Designer of the Niagara Type of Turbine Installed in Power-house Number One

The distributors and turbine wheels are divided into three stories. This system was adopted on account of the following advantages:

1. It allows the adaptation of a balanced gate, which is indispensable when an automatic governor is to be used.

2. The jets of water being radial, that is to say acting in a perpendicular direction to the turbine shaft, the pressure of the water is also perpendicular to this shaft, and does, therefore, not increase the pressure upon the step, this latter being able to support a limited weight only. A radial turbine has an unquestionable advantage over an axial one in this regard, especially in powerful turbines. These two advantages being very important determined the adoption of a radial turbine. The preference was given to an outward-flow turbine rather than to an inward-flow one for an economical reason, an outward flow turbine being much lighter and therefore cheaper. It is an easy matter to demonstrate this fact. The water, after passing through the turbine wheel giving up the greater part of its power, has to leave the wheel with a moderate speed in order not to waste an appreciable part of power in form of live force.

In an *outward-flow* turbine, the discharging surface is the outside circumference of the wheel, the distributor and wheel being at the *interior* of it. In an *inward-flow* turbine, the water has to be discharged at the interior of the wheel, and distributor and wheel have to be at the *exterior* of this same discharging surface. Consequently, they have to be larger and heavier and will be more expensive.

We have already mentioned that the adopted turbines are divided in three stories. The fixed and movable crowns instead of having buckets taking the whole height, have them divided into three parts by means of horizontal separations. Each story can be considered as a wheel proper, working when fully open with one-third of the whole water discharge of the wheel. Each story giving its maximum efficiency when it is entirely open, the turbine will have a good efficiency with one-third, two-thirds, and total gate opening. Between intervals the efficiency will diminish somewhat. With these divisions a turbine can, therefore, be obtained which gives a good efficiency with a partial discharge.

No special fly-wheel, as shown on the original design and that some engineers thought necessary, was provided for these turbines, because the revolving parts of the generator were heavy enough of themselves to provide the necessary momentum to maintain a steady rate of rotation of the hydro-electric machine, even upon a sudden change of load.

The working drawings of the turbine and governor and their installation, were completed in Geneva, Switzerland, in August, 1892, and were brought to The Cataract Construction Company on September 19, 1892, by Rudolphe Baumann, a Swiss engineer, the representative of Faesch and Piccard, of Geneva, who had been selected under the terms of their contract, to superintend and direct the construction, installation and putting into service of the turbines.

Mr. Baumann was especially qualified for this work, as he had collaborated with his firm in the development of the entire project, including all the details of construction and installation and the testing for fulfillment of the contractual guarantees, which included the following:

> That the mechanical efficiency of each turbine should be not less than 75 per cent at full gate, for the water discharged;
>
> That the whole plant should be so constructed, set up and put into service that it would operate in good working order;
>
> That the variation of speed of the turbines, more or less than the average speed, should not exceed two per cent in normal working, and should not exceed four per cent when the resistance should be suddenly varied 25 per cent.

It was explained that the change of speed of revolutions from 300 per minute, as first ordered and designed, to 250 per minute, made no other change in the design than to increase the diameter of the turbine 3.937 inches (0.10 m.). Theodore Turrettini, engineer of Geneva, was agreed upon as referee in all matters of difference, and his decisions were to be final and binding upon both parties.

CONTRACT AWARDED FOR CONSTRUCTION OF TURBINES IN PHILADELPHIA

It was not until November, 1892, that all details of this novel machine were determined, when the contract for the manufacture of two turbines of 5000 horse-power each was awarded, in a competition, to the I. P. Morris Company, of Philadelphia. By reason of the special construction of the governing mechanism, these novel machines, one governor for each turbine, were ordered from Faesch and Piccard, their designers, to be built in their own shops in Switzerland. An additional turbine, the third, was ordered from the I. P. Morris Company in 1893.

During the year 1893 much progress was made in determining the important details of the electric system. Approximate dimensions and weights were adopted and contracts awarded for three alternators.

The board of engineers and their engineering forces engaged in construction were disbanded January 1, 1893. They had completed their work pertaining to the tunnel, inlet-canal, wheel-pit slot, power-station, transformer-house, terminal railroad and Echota railroad station, water-works, Echota village, its cottages, drainage and sewerage system, local transmission line and minor structures.

In August, 1893, DeCourcy May, mechanical engineer, a recognized expert in the design and construction of heavy machinery, and late superintendent of the I. P. Morris Company of Philadelphia, joined the engineering forces at Niagara Falls, as assistant to the president of The Niagara Falls Power Company, and later as chief engineer of The Cataract Construction Company. He was charged with the preparation of the wheel-pit and power-house for the installation of the turbines and generators over which construction he had supervision as general superintendent until the operation of the first three power units in the autumn of 1895, when he resigned.

DeCourcy May
1851–1924
Mechanical Engineer
A.S.C.E., A.S.M.E.
Superintendent I. P. Morris Company,
Philadelphia
Assistant Chief Engineer
The Cataract Construction Company
The Niagara Falls Power Company
1893–1895

DeCourcy May, in charge of installation, reported January 20, 1894, that the wheel-pit was ready for the installation of the turbine machinery.

Mr. Baumann wrote September 17, 1895, that:

> The efficiency of the turbines and the regularity in speed being within the guaranty given by Messrs. Faesch and Piccard, I think that the conditions of their contract are also fulfilled, and beg you therefore to accept the two turbines mentioned.

PUBLIC CONFIDENCE MANIFESTED

Engineers and men of affairs who had closely watched the development of the plans, commenced to express their confidence in the enterprise; applications for power were increasing in number and were of a definite character; public interest had changed from curiosity to approval, and imitations of methods became noteworthy; Buffalo manifested impatience for power; and when it was officially announced that Turbines Numbers One and Two were completed and in good working order, the stockholders of the Niagara companies and the citizens of Niagara Falls rejoiced, relaxed their tension of more or less anxiety, and the executive officers, constituting the active management, were congratulated and gratified.

REORGANIZATION OF ENGINEERING STAFF

The personnel of the engineering staff was gradually changed at this period of 1892–1893, in preparation for the adoption and installation of the machinery to utilize the great hydraulic plant, that with its auxiliary structures and improvements was then approaching completion. With Dr. Sellers and De Courcy May, mechanical engineers, and George B. Burbank, civil engineer, the company was ably represented on the ground, and with consulting engineers available, Clemens Herschel at home and Col. Theodore Turrettini and Prof. W. Cawthorne Unwin abroad, counsel in hydraulics and mechanics was within quick communication and conference.

Prof. George Forbes, electrical engineer, of London, who had been awarded a first premium by the International Niagara Commission for his alternating current project for power distribution, was also at that time retained by The Cataract Construction Company, for a study of its opportunities for local and distant transmission of power.

FIRST POWER CUSTOMERS

(*a*) Water-power—Paper—Pulp

(*b*) Electrical Power—Aluminum

(*c*) Water Pumps—Potable Public Supply

The water of the power company's inlet-canal was first used by the International Paper Company upon turbines having an effective 3300 horse-power that was used directly, without electrical conversion, in the manufacture of wood pulp. These three turbines of 1100 horse-power each, were designed by Emil Geyelin and built by R. D. Wood & Company, of Philadelphia, and used chiefly for mechanical power. The use of hydraulic power only was also made by the Niagara Falls Water-Works Company to the extent of about 300 horse-power, by the use of Pelton water-wheels driving Riedler pumps.

The first electrical power, generated at, and distributed from, Power-house Number One, was about 5000 horse-power transmitted 0.46 mile to the Pittsburgh Reduction Company.[1]

The press announcements of the first installations, transmission and use of electrical power from the central station, Power-house Number One, attracted much attention, at home and abroad, and brought many inquiries, by correspondence and personal application for details of methods employed.

APPLICATIONS FOR ELECTRIC POWER

INCREASED UNITS INSTALLED

Applications for the lease or purchase of land for the erection of manufactories to use the electric power were made in increasing numbers and importance. These prompted The Cataract Construction Company to contract for additional turbines and for the extension of the power-house so as to provide the necessary space for a plant comprising ten turbines in all, of the same design and manufacture. The installation of these turbines of 5000 horse-power each, averaged two per annum from 1896 to 1900 both inclusive. They were of the Faesch and Piccard design, described as the Fourneyron type, double-wheel, outward discharge without draft tubes, and numbered respectively from one to ten, and all constructed by the I. P. Morris Company of Philadelphia.

POWER-HOUSE NUMBER TWO

Escher-Wyss Turbines

55,000 Horse-power

The increased demand for electrical power in 1899–1900 prompted The Cataract Construction Company to contract for (1) the erection of Power-house Number Two, on the easterly side of the inlet-canal and nearer to its mouth than the first central station and (2) eleven turbine units of 5000 horse-power each, of a total capacity of 55,000 horse-power.

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[1] Now the Aluminum Company of America.

Ground was broken on February 12, 1900, for the extension of the main discharge tunnel to the wheel-pit slot and Power-house Number Two.

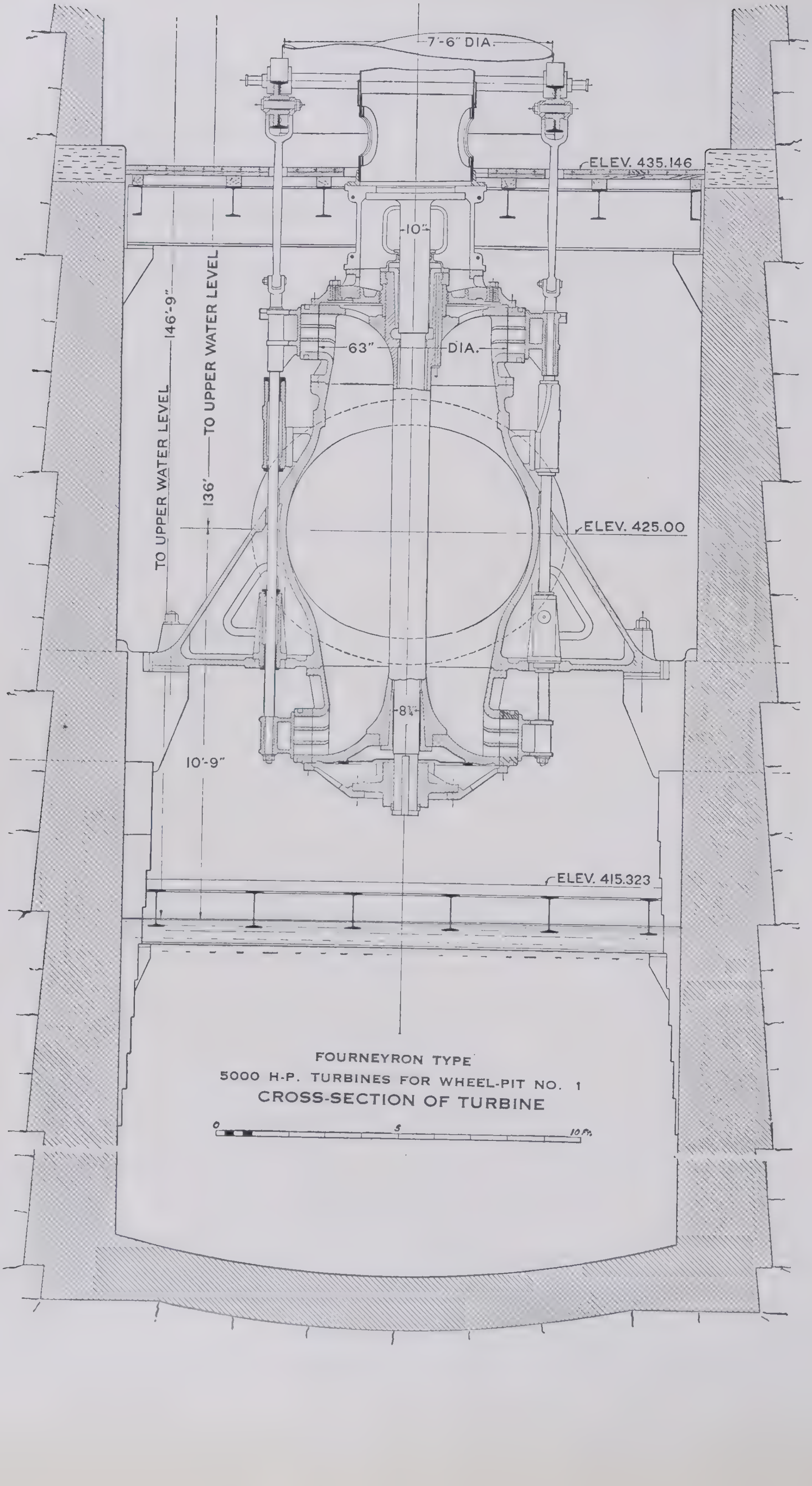
At this time it was considered good business policy to introduce the turbine design of Escher, Wyss & Company, into the plant. These turbines were guaranteed an efficiency, at least equal to that of the Faesch and Piccard wheels.

This encouragement of competition between Swiss turbine builders was deemed prudent and wise, especially while American turbine manufacturers were increasing their factory facilities and strengthening their engineering staffs of expert hydraulic designers and constructors, but which concerns were not then of sufficient experience and equipment to justify the risks involved in so large an expenditure as that required for an entire power-house, to be entirely composed of machines of identical design.

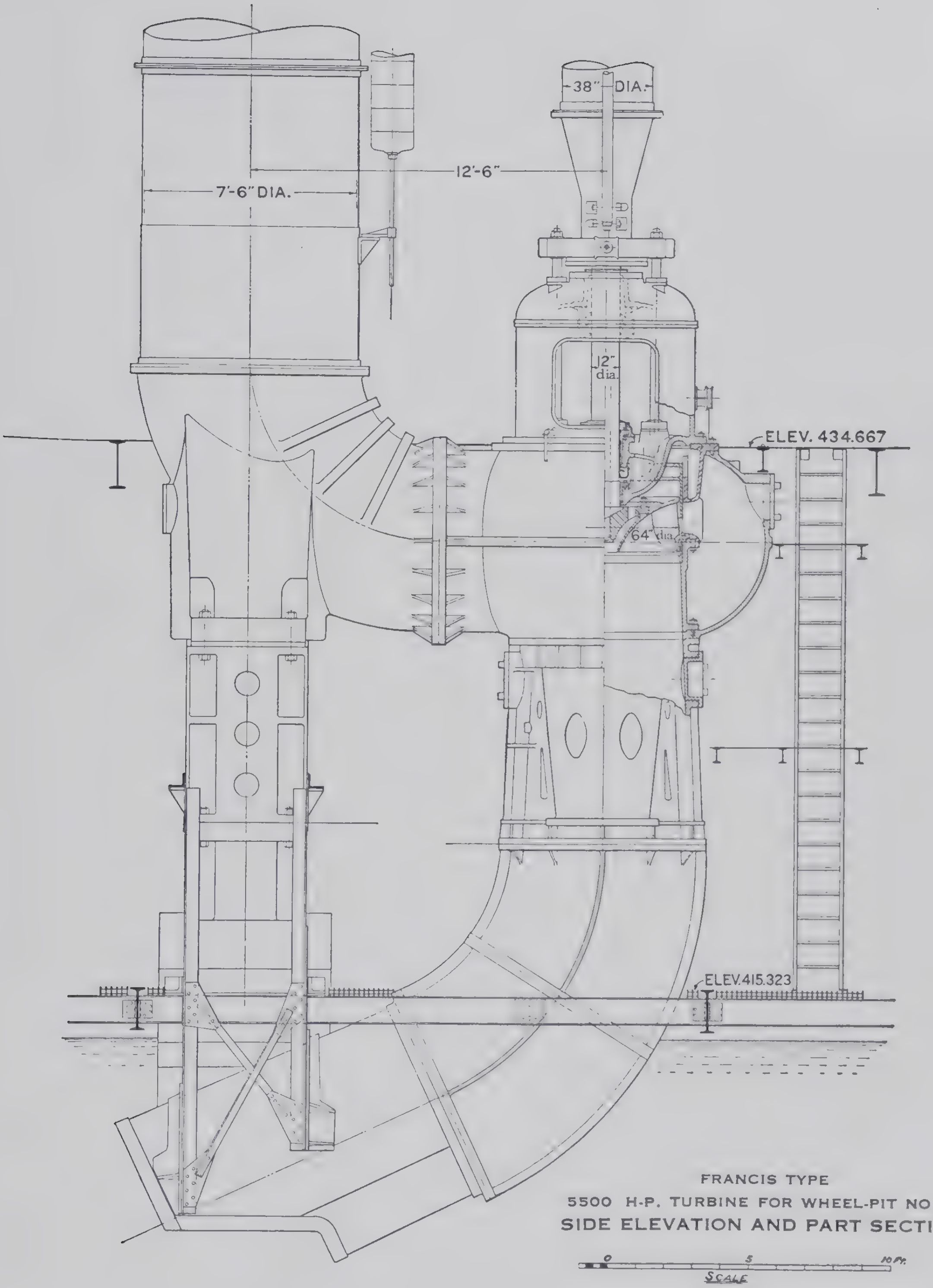
The turbines designed by Escher, Wyss & Company, of Zurich, were constructed by the I. P. Morris Company of Philadelphia. They differed from the Faesch and Piccard machines in the particular respects that they were of the Francis single-wheel, inward-flow type, discharging into a draft tube which branches into two sections, that run downward, back of the wheel-pit walls, and re-enter the wheel-pit at an angle of 45 degrees. Balancing pistons, on the lower end of the shaft, operating under water pressure, carry a large portion of the weight of the revolving parts of the units, while the remainder is carried on oil pressure thrust bearings.

Power-house Number Two differed but little in the arrangement of its machinery. The principal change was in the construction of the house itself, with a covered forebay and a deep subaqueous inlet as a protection against the surface accumulation of ice.

Power Unit Number 11, the first in Power-house Number Two, was in commercial service October 31, 1902. The entire installation was completed and the eleven units, excepting the reserve unit, Number 21, were placed in commercial service, as each unit became available; three units a total of 15,000 horse-power, in 1902; six units a total of 30,000 horse-power, in 1903; and two units a total of 10,000 horse-power, in 1904, a total of 55,000 horse-power in a period of three years.



FOURNEYRON TYPE
5000 H-P. TURBINES FOR WHEEL-PIT NO. 1
CROSS-SECTION OF TURBINE



FRANCIS TYPE
5500 H-P. TURBINE FOR WHEEL-PIT NO. 1
SIDE ELEVATION AND PART SECTION

CANADIAN POWER-HOUSE

TURBINE CAPACITY AND DESIGNERS

51,250 by Escher, Wyss & Company
57,750 by Charles C. Egbert

The location of a power-house in Canada, facilitated the construction of turbines in Switzerland, as they could be imported into Canada, where the custom-house duty was much less than in the United States.

Further experience with large hydro-electric units enabled the Niagara company to adopt still larger units in its third power-house in Canada. Careful study of Niagara and other turbines of foreign design since the installations in Power-house Number One had stimulated American manufacturers of responsibility to provide ample facilities for the construction of turbines according to the latest developments of hydraulic engineering. Ten turbines of a total capacity of 109,000[1] horse-power were installed in the Canadian plant. Five units, Numbers 1 to 5, of a total capacity of 51,250 horse-power were designed by Escher, Wyss & Company of which Numbers 1, 2 and 3 were constructed and installed by the Zurich firm in 1905 and Numbers 4 and 5 by the I. P. Morris Company in 1906. The remaining five turbines were designed by Charles C. Egbert, consulting mechanical engineer, of Niagara Falls, New York. Two of 12,750 horse-power each were constructed and installed by the Bethlehem Steel Company, of Pennsylvania; Number 6 in 1910 and Number 7 in 1913. Three of 10,750 horse-power each were constructed and installed by Wellman, Seaver, Morgan & Company, of Cleveland, Ohio; Numbers 8 and 9 in 1916 and Number 10 in 1917.

The Escher, Wyss & Company turbines for the Canadian plant were similar in design to the Francis inward-flow type designed by that house for the eleven units installed in Power-house Number Two.

The five turbines designed by Charles C. Egbert were designed to conform to existing wheel-pit conditions. The wheel-pit had been completed for the installation of Units Numbers 6 to 10 inclusive, which were to be the same as Units Numbers 1 to 5 and to give 6500 horse-power more than those already installed. In order to do this the Turbines Six and Seven were built with two spiral wheel-cases. The upper one discharges through the draft tubes which had been built into the wheel-pit walls and the lower one through a center draft tube directly into the wheel-pit.

Turbines Eight, Nine and Ten were similar to Units Numbers 6 and 7 but they were designed to give greater efficiency by eliminating the double lower penstock elbow where the losses were rather large. The discharge from the single spiral steel case is through a draft tube moulded in the concrete arch which spans the wheel-pit and supports the turbine. All the weight of the revolving parts is carried by oil pressure thrust bearings in each of the five Egbert turbines. The speed of all these turbines is controlled by cylinder gates located between the runner and the guide vanes. They are moved vertically by the governors located on the generator floor, through a series of rods and levers.

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[1] An additional 12,000 horse-power unit was installed in 1924 bringing the total rated capacity to 121,000 horse-power in the Canadian power-house.

CONSIDERATIONS LEADING TO REPLACEMENTS IN POWER-HOUSE NUMBER ONE

The considerations of safety that directed the design of the ten turbines of Power-house Number One in 1895–1900 and the experiences in their operation that prompted their reconstruction in 1910–1913, with a 10 per cent increase in efficiency, are of interest here, as one of the important improvements found desirable in the great and novel system adopted in 1892.

WATER WITHOUT LIMIT

Nearly all statements made, by way of encouraging favorable consideration of plans to develop Niagara power, have used the phrase, "unlimited power" in referring to the volume of water flowing in Niagara River, over its great natural dam, and creating the Great Falls, the "unlimited" source of power.

The right to avail of this great volume of water was believed to be the inherent right, under the general laws of the State of New York, that was inseparable from the ownership of uplands bordering upon streams, to use the water as the riparian rights pertaining to the adjoining lands under water to the middle of the river bed. As the proposed diversion of water by The Niagara Falls Power Company included provision for its restoration to the river from the shore lands of that company, below the falls, this riparian right was considered a definite, important and fundamental right in marshalling the assets of the enterprise and planning for their utilization in the development of Niagara power. In reliance upon this abundance of water the engineers proceeded with plans, always making liberal allowances when in doubt as to the results of using such very large and novel machines as proposed in utilizing the large quantities of water available for power purposes.

Safety of operation and repair, and continuity of output were considered of the greatest importance in the scheme of installation. The desirability, if not the necessity, of frequent examination of the installations when in operation, prompted various precautions, of which a few may be mentioned.

LOCATION OF TURBINES AND TUNNEL

The grade of the tunnel and the depth of the wheel-pit were established so as to permit personal examinations of each turbine, without the necessity of shutting down its neighbors, with the least interruption to the service and the avoidance of danger to the inspectors.

With the adoption of the plan of a central station or power-house, there followed the abandonment of the project for four turbo-electric machines in a single wheel-pit and in lieu thereof the arrangement of the machines in line, parallel and near to the inlet-canal, so that each machine was operated as an independent and complete unit.

In locating the turbines, ten in a row, it was first proposed that as each turbine had its own penstock connection with the inlet-canal, each should likewise have its separate discharge conduit connection with a general service or tail-race tunnel, parallel with and back of the wheel-pit slot, that would provide for all turbines a connection with the main tail-race or discharge tunnel. This greatly increased the necessary rock excavations.

As the wheel-pit required, as a measure of safety, its own direct connection with the main tunnel, it was determined to omit the common tail-race service canal and give each turbine its own downward discharge directly into the wheel-pit tail-race, whence such waters would unite and flow through the short curved tunnel connecting the wheel-pit with the main discharge tunnel.

As the head of water and its volume were considered more than ample for the work intended, the turbines were located 10 feet 9 inches above the water level in the tail-race. Notwithstanding this provision, it is stated by L. E. Imlay, superintendent of operations of the plant, that during the operation of both power-houses the tail water rose so that the lower parts of the Fourneyron, the first Niagara turbines, were often practically submerged, preventing access to the interior so that when repairs had to be made the load had to be reduced.

While this location as shown decreased the available head or fall to about 136 feet, it was thought to have three advantages, viz.:

1. It should protect the turbines from being submerged by an influx of water from the tunnel, arising from a sudden rise in the water level of the river from ice jams or other causes, or from the accumulation of huge air pockets from wave currents in the flowing water of the tunnel;
2. It should permit an examination of any one or more turbines, and their being taken apart or repaired above the water, without

interfering with the operation of the other turbines at the same time; and

3. It was economical in avoiding an expenditure for a service canal tunnel that possibly might be only a temporary expedient.

The above indicated decisions were made prior to the enactment by the New York State Legislature of the amendments to the charter of The Niagara Falls Power Company, including the provision limiting its right to divert water from the river for power purposes to not exceeding 200,000 effective horse-power. This curtailment of riparian rights was not then considered as serious to the company's expansion as it became about ten years later, as the experimental character of the undertaking was still uncertain, and the demand for electrical power awaited the subsequent demonstration of its control and utility.

OPERATION OF POWER-HOUSE NUMBER ONE

Early in January, 1900, Dr. Coleman Sellers, chief engineer, and his associated engineers, Clemens Herschel, hydraulic engineer, Lewis B. Stillwell, electrical engineer, W. A. Brackenridge, division engineer, and Albert H. Porter, resident engineer, prepared a memorandum regarding the operation of Power-house Number One, as a guide in formulating the designs for the hydro-electric equipment of Power-house Number Two. The improvements suggested to quicken the currents of discharge in the wheel-pit and through the branch tunnel to the main discharge tunnel were calculated to improve turbine efficiency, as would the proposal to extend the main tunnel to Power-house Number Two, of the same size for the entire distance, and eliminate the short extension, previously constructed of a contracted area.

EGBERT'S SUGGESTIONS FOR TURBINE IMPROVEMENT

The severe tests of the machinery during the winter, 1898–1899, of unprecedented severity, with conditions that were not fully taken into consideration when the hydraulic part of the machine was being built, prompted suggestion for modifications that would anticipate the freezing of the water in the canal to such depths that dynamite only could break it up, and the forming of anchor ice that would encrust the racks guarding the inlet to the penstocks, so that almost no water could pass the bars.

Provision for easy and prompt access to the wheel-cases was found necessary in order to remove therefrom logs, tools, large pieces of cloth, clothing, bark, small stones, compacted ice, etc., that from time to time, choked the distributors of the lower wheels.

Numerous other modifications of design for the turbines in Power-house Number Two were urged for careful consideration. The suggestion was made that further operations should be carefully noted for future use when the pressing requirements of customers had been more nearly provided for than at that time, by the commencement of operations in the proposed Canadian plant, as well as in Power-house Number Two, before interrupting the production in Power-house Number One, as was considered necessary to effect the changes thought to be desirable.

Charles C. Egbert,[1] mechanical engineer of The Niagara Falls Power Company, who had spent much time abroad in becoming familiar with the latest turbine practise of continental engineers, and who had acquired several years' experience in the design, construction and operation of the Niagara plant, called attention to the advantages that could be gained by the reconstruction of the turbines in Power-house Number One. During the design and construction of the five 10,000 horse-power turbines of the Canadian plant under the contract with Escher, Wyss & Company, Mr. Egbert, who had been named in the contract as the official inspector for The Niagara Falls Power Company, resided in Zurich and participated in the testing of materials and the inspection of the construction as it progressed in the shops.

In April, 1907, he submitted his suggestions for increasing the efficiency of the double wheel turbines in Wheel-pit Number One. He expressed his confidence that it would be practicable to replace the existing Fourneyron turbine units Numbers 1 to 10 with single-wheel Francis turbines set higher in the wheel-pit, using the original foundation castings for the reconstructed machines. He proposed to equip the new machines with draft tubes, which would have the effect not only of increasing the efficiency of the turbine but of lowering somewhat the water levels in the wheel-pit, thereby increasing the output of the wheel-pit in a substantial degree.

REPLACEMENT OF ORIGINAL TURBINES IN POWER-HOUSE NUMBER ONE

In October, 1908, Mr. Egbert reported that he considered the time ripe to take up seriously the subject of turbine replacement as previously suggested.

The Canadian plant had 51,250 horse-power in service at that time. The demand for additional power from old and new customers was still increasing. He now believed that the desired improvements could be made without shutting down Power-house Number One and at a comparatively small expense. The following statement was made by Mr. Egbert in advocating that he be authorized to prepare his working drawings for the reconstruction of one turbine unit as he had described.

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[1] See Volume I, page 287.

The output of the present plant of the company is limited, first, by its physical capacity; second, by the Burton Act. In both cases the largest returns on the investment will be obtained by having the most efficient machinery, provided the output can be sold. This also holds if, in the future, it is found advisable to construct a second tunnel.

The Burton Act, permits us to divert 8600 cubic feet of water per second. The paper mill uses, say, 700 cubic feet per second which leaves 7900 cubic feet per second for the development of power in Power-houses Numbers One and Two. By substituting Francis type of turbines with draft tubes in place of the Fourneyron type of turbines now in Wheel-pit Number One and operating all the turbines running at 70 per cent or more valve opening, it will be possible to generate upwards of 85,000 electric horse-power in the two power-houses, or about 20,000 electric horse-power more than is now considered available. The increase in output will result (1) from the greater efficiency of the new turbines; (2) from the utilization of the entire head between head water and tail-race; (3) from the lowering of tail water in Wheel-pit Number One by pointing the discharge from the draft tubes down stream, and (4) from the possibility of loading the units more economically.

Mr. Egbert estimated that the turbines of the type proposed and indicated by the drawing on page 119 could be installed at a cost of about $30,000 per unit, and that such additional power in that power-house could be obtained more cheaply and more quickly than by the installation of additional units in the Canadian plant.

The authority to prepare the working drawings was given to Mr. Egbert, as he had requested, and contracts were entered into by The Niagara Falls Power Company with the Bethlehem Steel Company for the reconstruction of one unit which was duly installed October, 1910. Its successful installation without disturbing the operation of the other units in the wheel-pit slot and its realization of all that its designer had promised in resumption of service, led to the placing of a single order for nine additional turbines of the same design. The replacements were made, one unit at a time, in

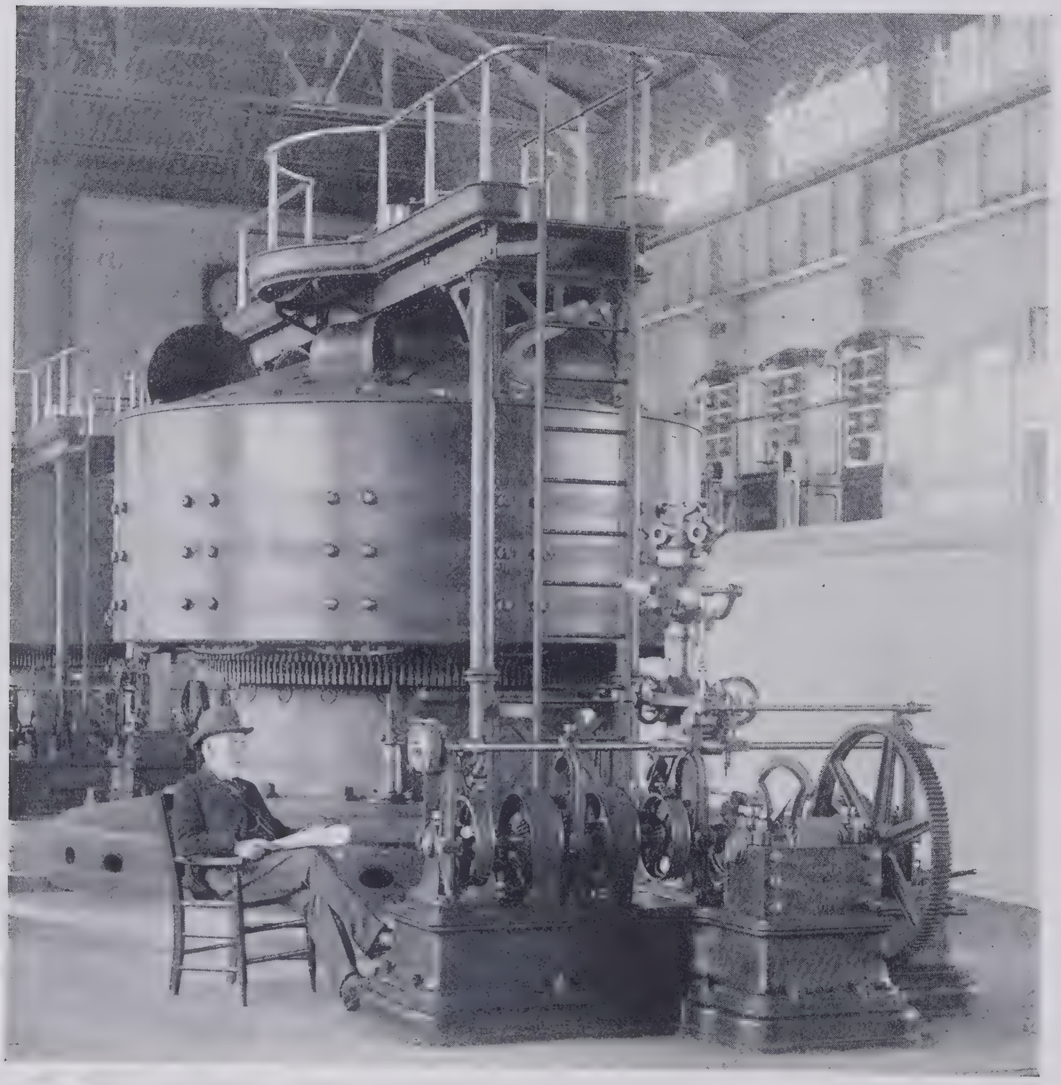
	Units
1910	1
1911	3
1912	5
1913	1
Total units	10

Total rated capacity 50,000 horse-power.

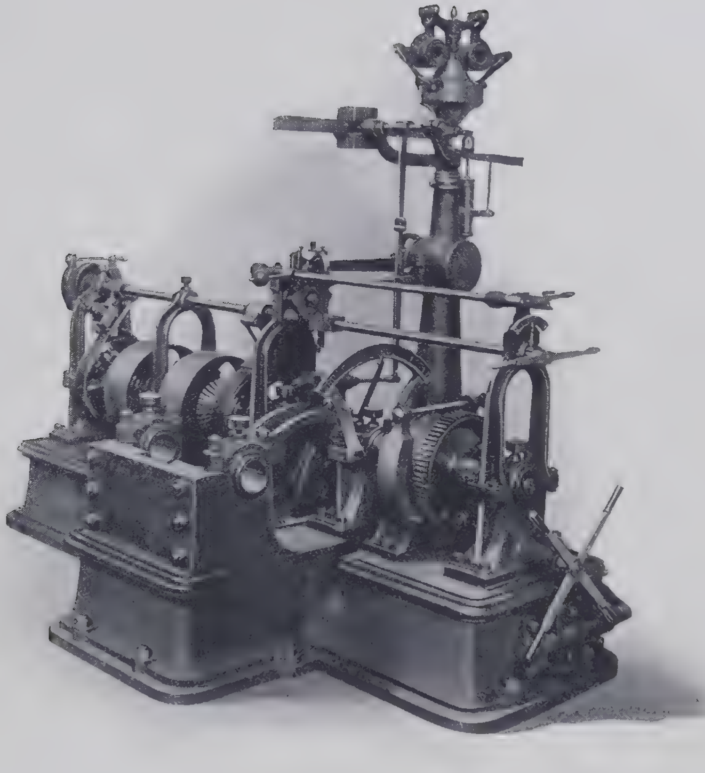
The total expenditure for this reconstruction was $447,000, including the substitution of steel in place of wooden decks in the wheel-pit, which was not considered when first estimating the total cost.

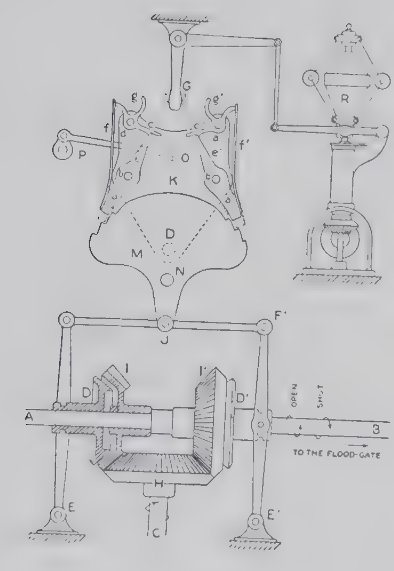
GOVERNORS

The regulation of the speed of the first three hydro-electric units was secured by the action of the mechanical governors designed and built by Faesch and Piccard of Geneva, Switzerland, for connection to the turbines designed by them and constructed by I. P. Morris & Company of Philadelphia. These were applied to the turbo-generator power units, Numbers 1, 2 and 3

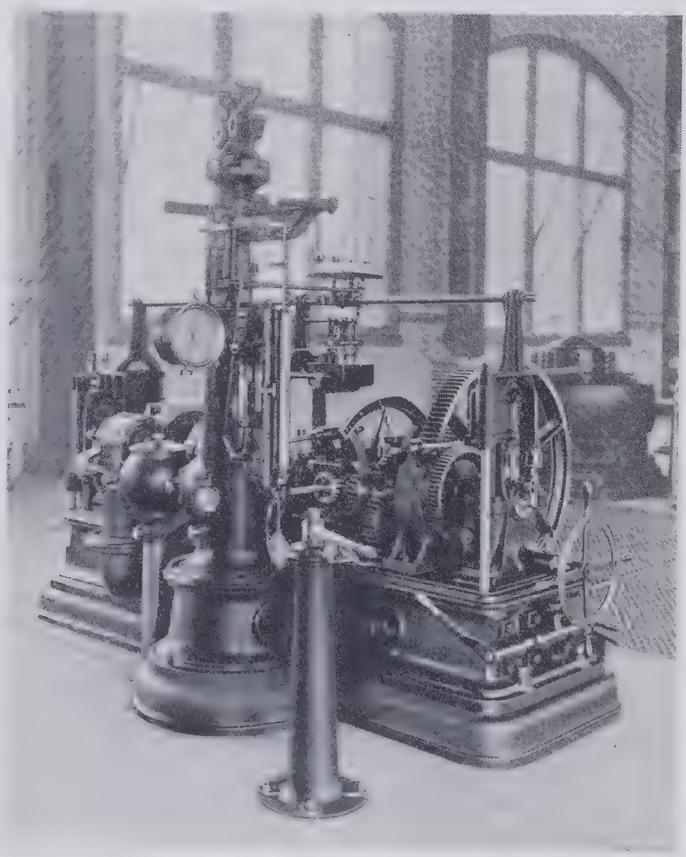


Dr. Coleman Sellers Watching the Operation of the Faesch and Piccard Governors Used on the First Three Turbo-generator Power Units in Power-house Number One





Mechanical Governor Designed by Faesch and Piccard and Used on the First Three Turbo-generator Power Units in Power-house Number One (with Diagram) in Power-house Number One. These mechanical governors operated satisfactorily and remained in use for fifteen years. They attracted much attention from expert mechanicians who recognized their ingenious devices for the special purposes for which they were designed.



Electric Governor Designed by Dr. Coleman Sellers and Used on the Last Seven of the Ten Original Turbo-generator Power Units Installed in Power-house Number One

The remaining seven turbo-electric units of Power-house Number One were governed by the electric machines devised by Dr. Coleman Sellers, chief engineer of The Niagara Falls Power Company and constructed by William Sellers & Company of Philadelphia.

These two types of governors were practically similar in the respect that their application of power to the gate rack was made through a train of gears driven from the main shaft of the turbine. The difference between these two types of governors is described by an engineer[1] familiar with their operation as follows:

> In the Faesch and Piccard governors the application of power in either direction to the gate rack was controlled by means of two friction clutches actuated by the fly-balls through a pawl and ratchet device, while in the Sellers governors the same was accomplished by means of two magnetic clutches actuated by the fly-balls through electrical contacts.
>
> Of the two types, the Faesch and Piccard was superior, because it performed as well, if not better, than the Sellers type, and was simpler and easier to adjust and maintain in good working order. The magnetic clutches of the electrical governor was due to residual magnetism in the former after the current was cut off.

All of the ten governors, three mechanical and seven electric, were mechanically operated by direct connection to the main shaft of the unit and were in continual use until, commencing in 1910, the ten turbines were successfully changed from the original Fourneyron outward-flow type of double wheel to the Francis single wheel inward-flow type with draft tubes.

At the time when the Francis type turbines were substituted for the Fourneyron type turbines in Power-house Number One, there had already been installed in Power-house Number Two and in the Canadian plant, fifteen governors of the oil-pressure type which at that period had generally superseded the mechanical type for regulating water turbines. With the purpose of having all governors in the three plants of uniform design, it was considered best to discard the mechanical and electrical governors and equip the new turbines in Power-house Number One with the Escher, Wyss & Company oil-pressure type.

These new governors are like those especially designed by Escher, Wyss & Company for the turbines of their design in Power-house Number Two and in the Canadian plant. They are operated by high pressure oil acting on one side of a piston to open the gate in the turbine. Counter-weights acting in the opposite direction close the gate. The flow of oil to and from the governor cylinder is controlled by a regulating valve operated by the fly-balls through a pilot valve. These governors and their turbines have continued in successful operation up to the present time.

The Escher, Wyss & Company governors were so thoroughly satisfactory that upon the completion of the plants, there were thirty-one in use.

SUMMARY OF TURBINE POWER IN THE THREE PLANTS

The largest turbine in use anywhere in 1890, when The Cataract Construction Company commenced the consideration of its problems, was probably less than 1000 horse-power and the largest were by Swiss engineers.

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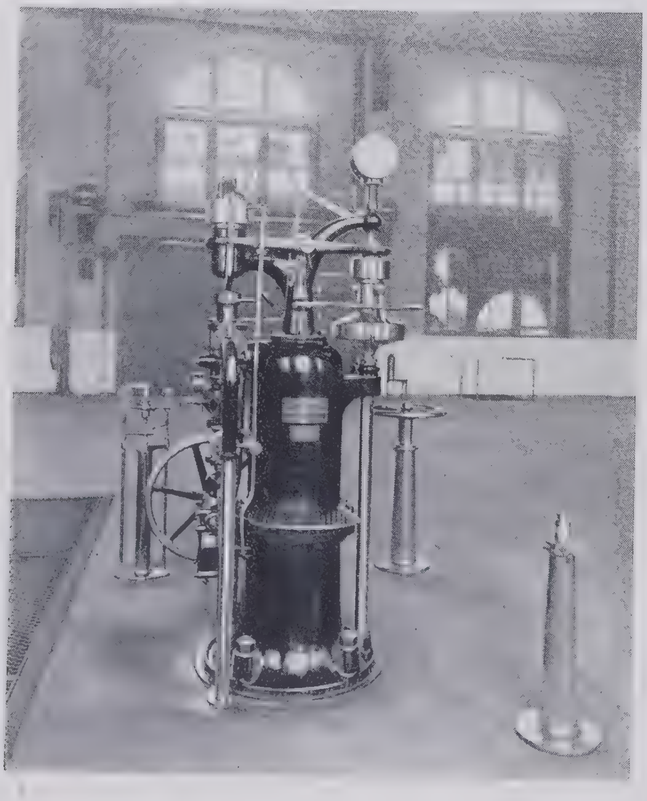
[1] Charles C. Egbert.

In 1891, The Cataract Construction Company called for designs for 5000 horse-power units and authorized their construction for Power-house Number One early in 1892. The first installation of 10,000 horse-power, of two units of 5000 horse-power each, was put into commercial service August 26, 1895. This service increased progressively as additional turbines were ready for operation, until there were ten turbines with a total capacity of 50,000 horse-power.



Governor Designed by Escher, Wyss & Company in Use on All Turbo-generator Units in Power-houses One and Two and in the Canadian Niagara Plant at the Present Time (1927)

Of the 109,000 horse-power in the Canadian plant, 51,250 was in service in a period of two years and 57,750 horse-power in five years.

In Power-house Number Two the turbine unit was 5000 horse-power making the entire installation of eleven units, 55,000 horse-power.

The ten original units of Power-house Number One were replaced with increase in efficiency in the years 1910 to 1913.

The thirty-one turbines[1] in the Niagara and Canadian plants of The Niagara Falls Power Company of 1886 are rated as follows:

Power-house	*Units*	*Capacity*	*Total Power*
No. 1	10	5,000	50,000
No. 2	11	5,000	55,000
No. 3[2]	5	10,250	51,250
	2	12,750	25,500
	3	10,750	32,250

Totals—31 turbines of 214,000 horse-power
an average per turbine of 6,903 horse-power

The type of wheel of the entire plant of thirty-one[1] turbines is the *Francis inward-discharge turbine,* but there are several variations of this simple description.

All the twenty-one turbines in Power-houses Numbers One and Two are of the *single-wheel* construction, discharging *downward*, and of 5500 horse-power each.

In the Canadian power-house there are greater variations. All of the smaller (10,250) units have double wheels, the nether wheel discharging upwards, while the upper wheel discharges downward. Two of the larger (12,750) turbines have double wheels, both discharging downward. Three of the larger (10,750) class have single wheels that discharge downward.

The science of hydraulics and the art of its application, as practised abroad prior to 1895, were brought by The Niagara Falls Power Company to the United States, where, in their utilization of water-power, they have developed during the past thirty years a vast industry, that conserves the coal of the country and has added great wealth and prosperity to the nation.

In May, 1922, the commissioners of the Queen Victoria Niagara Falls Park reported the installation at Queenstown of the first 50,000 horse-power unit of the Hydro-Electric Power Commission and stated that

> The latest plant appears to mark a long advance in the manufacture of supersized turbines and generators and indicates that the 5000 to 15,000 horse-power units of the last twenty years will give place in special installations to units that may reach 100,000 horse-power each.

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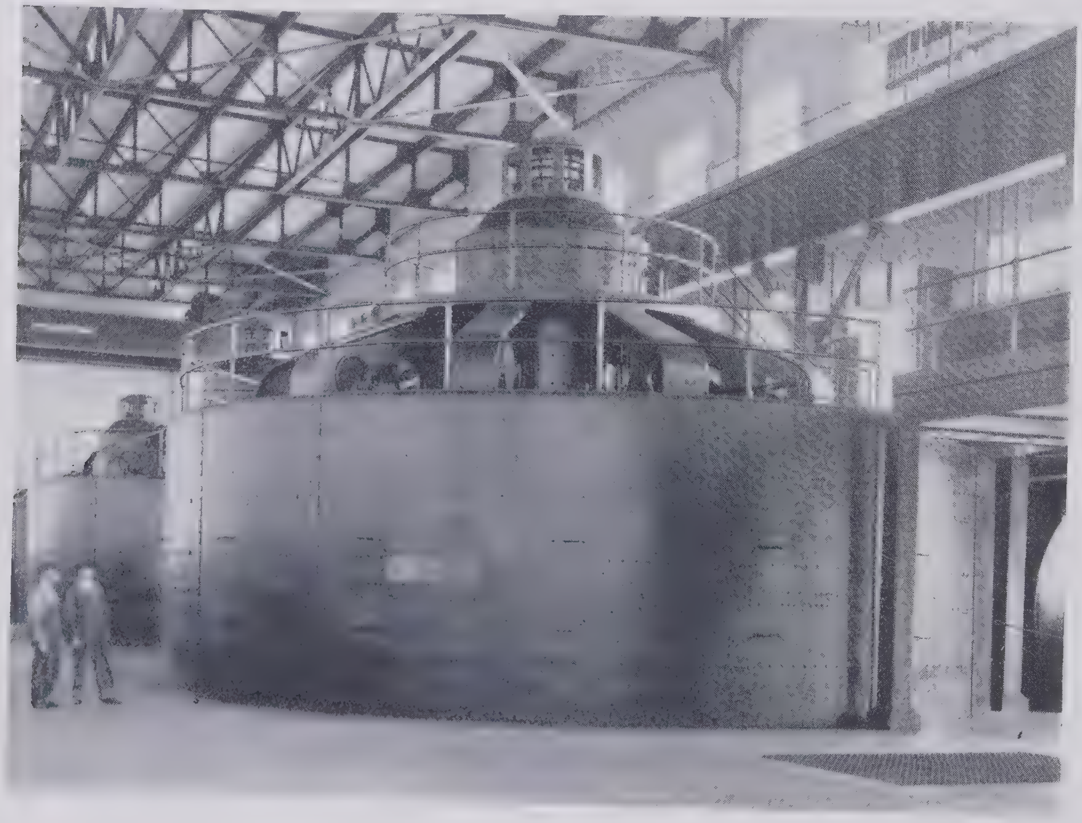
[1] For detailed descriptions of individual turbines see Appendix P.

[2] An additional 12,000 horse-power reserve unit was installed in the Canadian-Niagara plant during 1924, bringing the total capacity to 226,000 horse-power.

THE "GREAT TRIUMVIRATE" OF POWER IN HYDRAULIC STATION 3-C

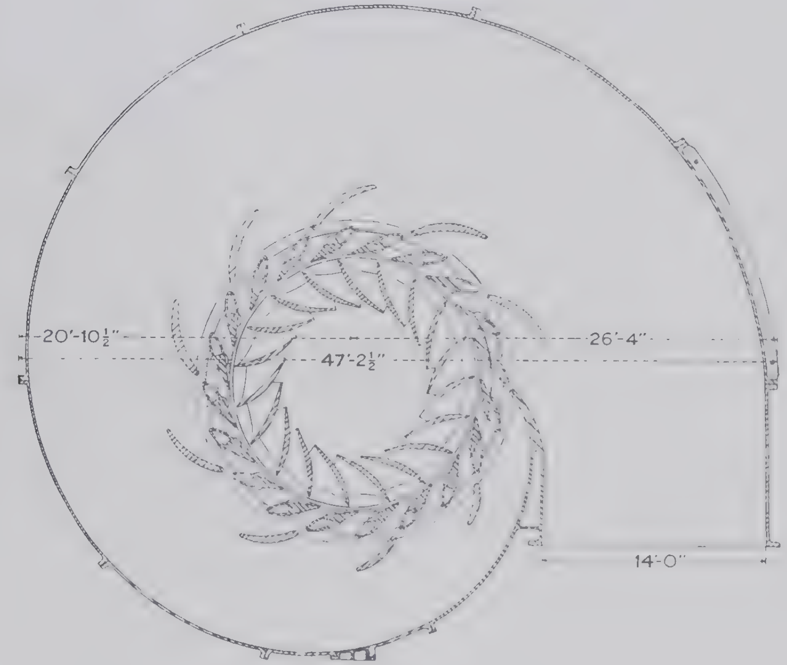
The Niagara Falls Power Company, MCMXVIII, installed in August, 1923, the first of three hydro-electric units vertical type of 70,000 horse-power each in its Power-house Number 3-C, and thereby maintains up to the present date the leadership in the development of the art of turbine design and construction that was taken by The Niagara Falls Power Company of 1890.



Three 70,000 Horse-power Units in Station 3-C

The 70,000 horse-power hydro-electric units had never been assembled or operated previous to their final installation in the power-house. The cast steel turbine cases were assembled in the shop and given a hydrostatic test before being shipped, and the plate steel case was bolted up in the shop and the rivet holes reamed. All three generators were assembled and wound in the power-house.

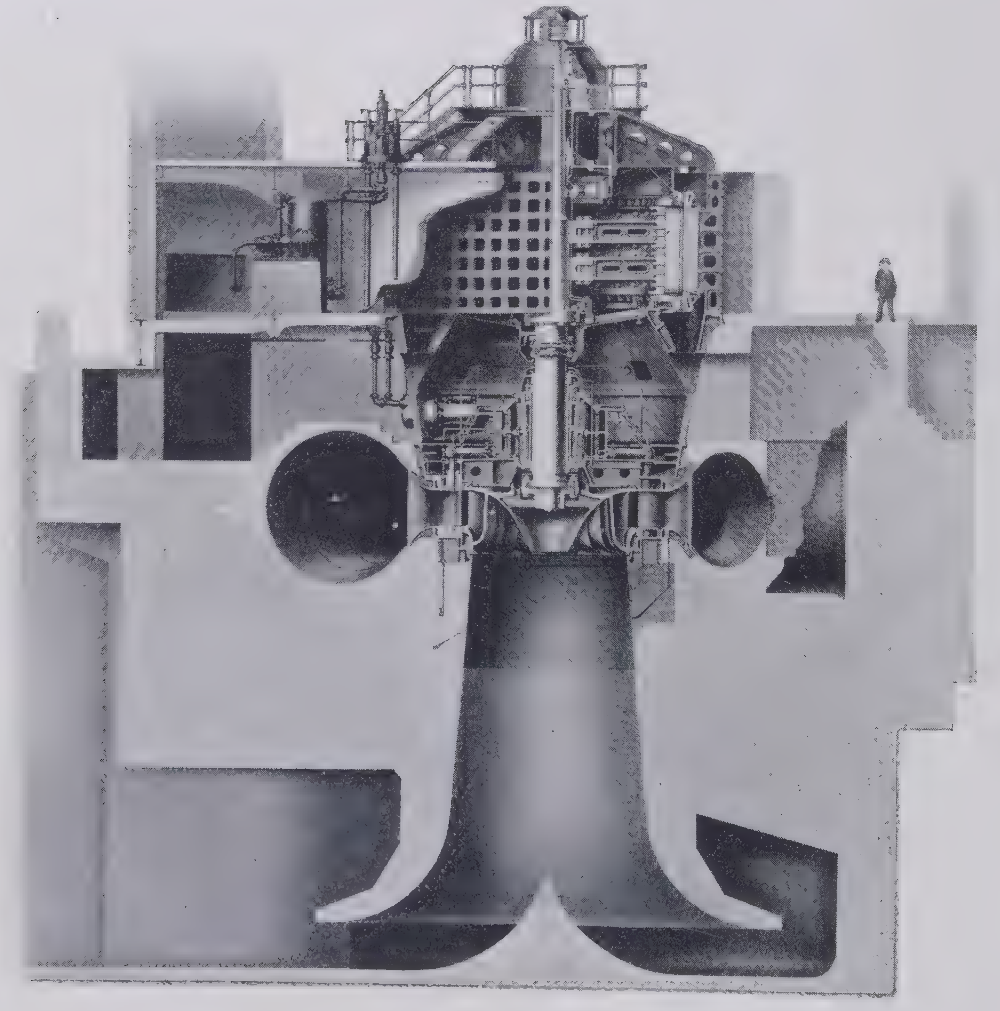
Each unit functioned properly the first time water was admitted through the wheel-case. Very shortly after the first turnover each was placed in service and carried its full load; Number 1 on December 18, 1923, Number 2 on June 1, 1924, and Number 3 on September 1, 1924. It is to the credit of the engineers of the manufacturing companies who furnished the apparatus and the engineers of The Niagara Falls Power Company, MCMXVIII, who designed and built the foundations and settings that these exceptionally large units went together and into operation so satisfactorily.



Plan Showing Relation of Casing, Speed Ring, Guide Vanes and Runner of 70,000 Horse-power Turbine in Power-house Number 3-C of The Niagara Falls Power Company, MCMXVIII

Head 213.5 Feet *Speed 107 R.P.M.*

Designed and constructed by the I. P. Morris Department of the William Cramp & Sons Ship & Engine Building Company of Philadelphia, Pennsylvania, who have built 69 turbines of a total rated capacity of 1,055,200 horse-power for the various plants at Niagara Falls.



The Modern Water-engine

THE LARGEST HYDRAULIC PRIME MOVER IN THE WORLD

A combined hydro-electric unit designed and built by Allis-Chalmers Manufacturing Company, of Milwaukee, Wisconsin, for The Niagara Falls Power Company. This unit is rated 70,000 h-p., 213 feet head, 65,000 kv-a., 12,000 volts, 3-phase 25 cycles, 107 r.p.m. Developed 82,000 h-p. under test when first installed. Rotating weight over 700,000 lbs. The designer of this machine recently stated[1] *publicly his belief that units of 100,000 horse-power are feasible.*

SPECIAL FEATURES

- *Hydraucone draft tube.*
- *Plate steel spiral casing.*
- *Direct-connected flyballs.*
- *Viscosity type oil pumps.*
- *Brake supporting ring forming passage for ventilating air.*

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[1] William Monroe White, manager and chief engineer, hydraulic department, Allis-Chalmers Manufacturing Company, December 19, 1923, before the Boston Society of Civil Engineers.

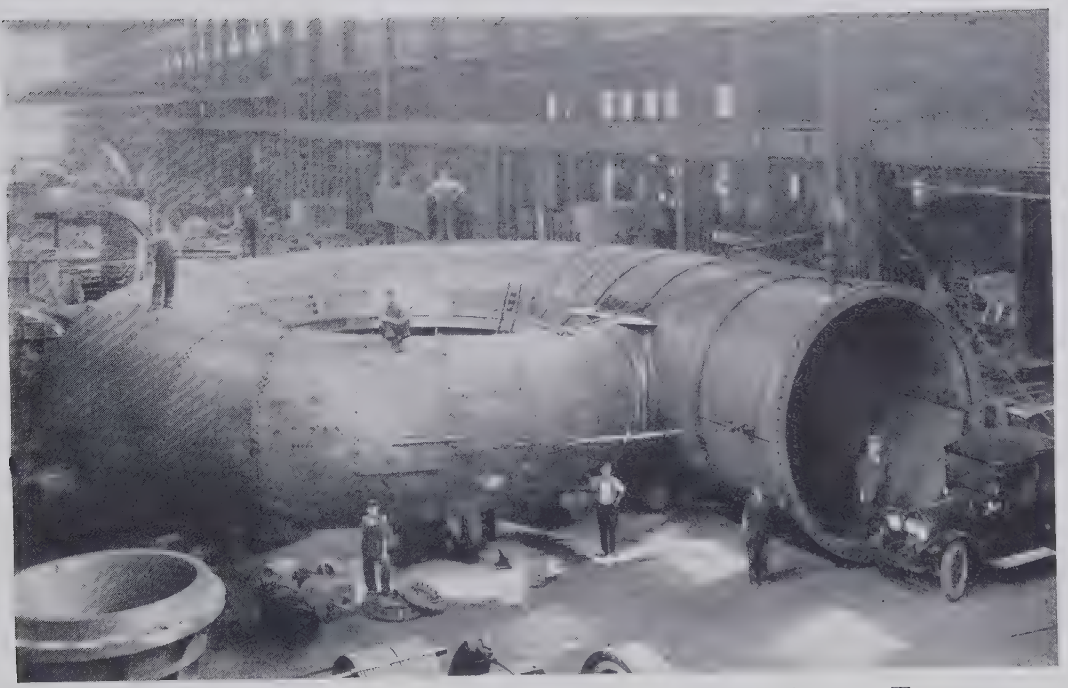
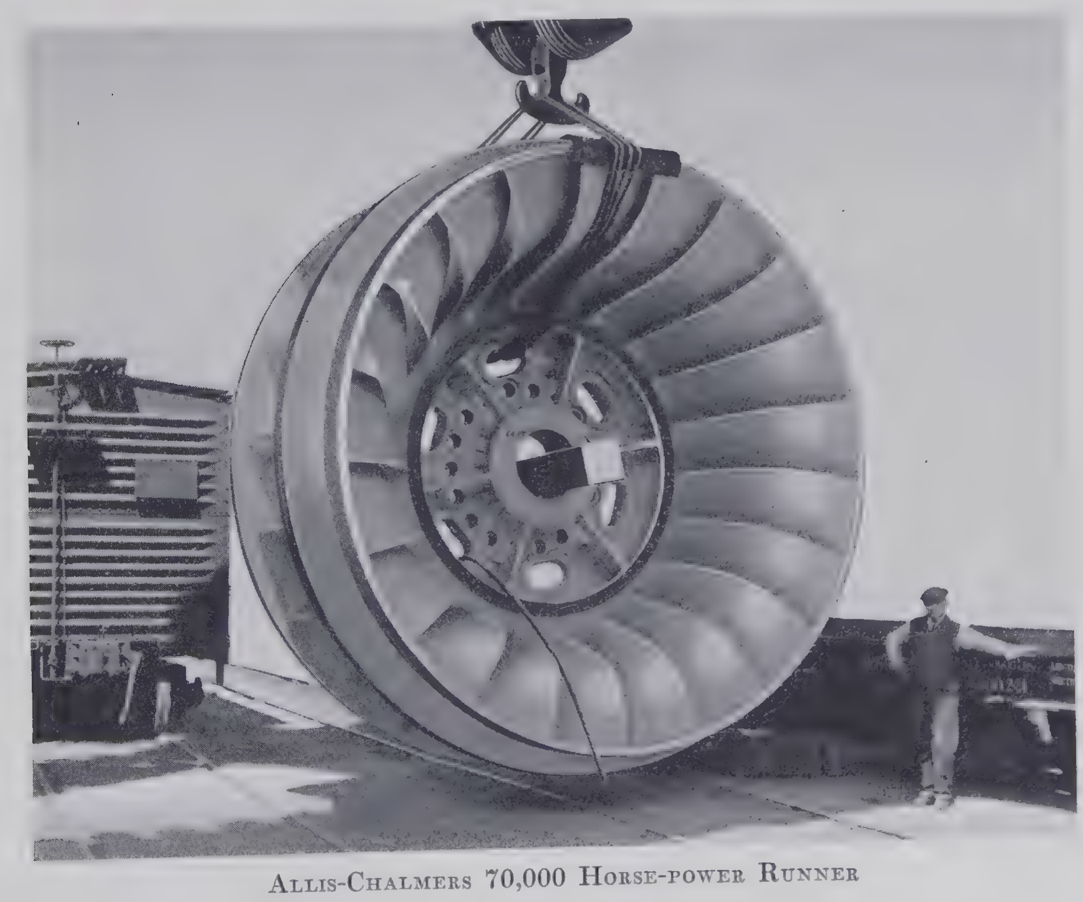
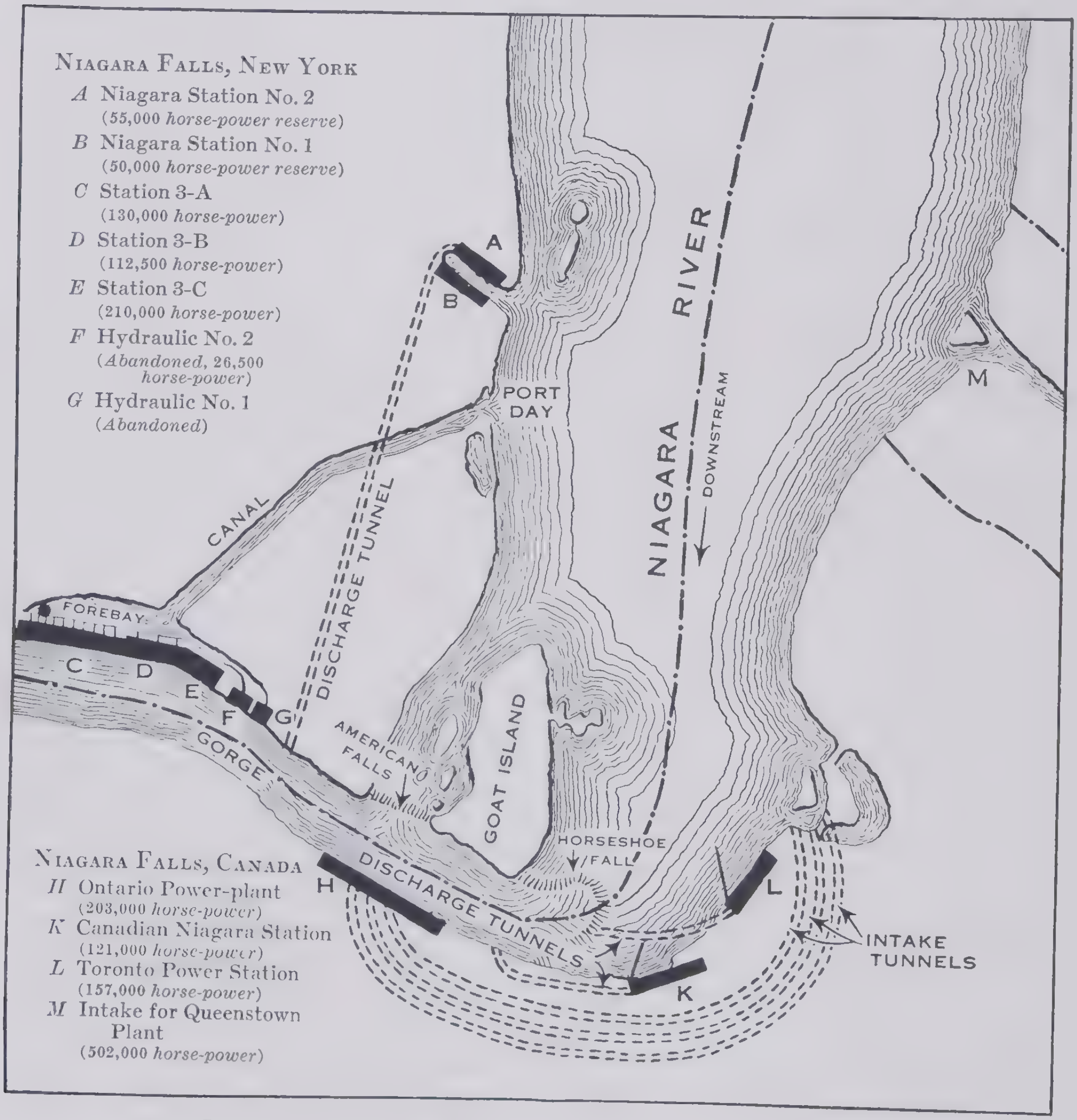


Plate Steel Spiral Casing for 70,000 Horse-power Niagara Turbine



Allis-Chalmers 70,000 Horse-power Runner

The leadership of the entire country in the output of electrical energy, early established by The Niagara Falls Power Company, has been consistently maintained up to the present time, under the Schoellkopf management. The consolidated Niagara Falls Power Company produced in 1926 a total of 3,295,780,791 kilowatt-hours of electrical energy from Niagara waters, that otherwise would have gone "over the dam" to the sea, been wasted and never missed. By utilizing the waters of Niagara, the company developed power



LOCATION OF POWER-PLANTS AT NIAGARA FALLS, 1927 that would otherwise have required 3,295,780 tons of coal, a fuel that would have cost $6.50 per ton at Buffalo, or $21,422,570.

The total rated, installed capacity of the several plants of The Niagara Falls Power Company, MCMXVIII, in September, 1926, was 678,500 horse-power. Five turbines representing a total of 50,000 horse-power have attached to them direct-current generators owned by the Aluminum Company of America, and this 50,000 horse-power is sold as mechanical energy. The turbines representing the remaining 628,500 horse-power are attached to alternating-current generator equipment having a total capacity of 466,275 kilowatts.

During 1927, the board of directors of The Niagara Falls Power Company, by resolution, named the principal power-houses and sub-stations of the company for, and in appreciation of, those men who pioneered the great Niagara power industry, and developed it to its present state of perfected service to the public.

FORMER NAMES	NEW NAMES
NIAGARA POWER STATIONS, NUMBERS ONE AND TWO	THE EDWARD DEAN ADAMS STATION
CANADIAN NIAGARA STATION	THE WILLIAM B. RANKINE STATION
HYDRAULIC STATIONS (3-A, 3-B, AND 3-C)	THE SCHOELLKOPF STATION
ECHOTA SUB-STATION	THE JOHN LYELL HARPER SUB-STATION

ICE

ITS POWER, DANGER, AND CONTROL

CHAPTER XX

Niagara Falls in Winter

ICE

ITS POWER, DANGER, AND CONTROL

CHAPTER XX

CONTINUITY ESSENTIAL

IN formulating plans for the production, sale and delivery of electricity for use as light and power, essentially dependent upon uninterrupted and undiminished supply, it was appreciated that the necessity of continuous service through a series of simultaneous or consecutive operations requires an absolute co-ordination of all parts of the series, and of none more assuredly than the first part, the uninterrupted supply of the raw material, flowing water.

In the various electrochemical and electro-metallurgical processes that have been developed at Niagara, continuity of heat in nearly all cases, is absolutely essential to successful operations of furnaces and other applications of electric heat to assembled materials, prepared for treatment by fusion.

The vast watershed of the Great Lakes would afford ample insurance against failure of the supply through drought; but after investigation it was realized that a more serious danger would be encountered in the accumulation of ice at the inlet to the hydraulic machinery. It was therefore considered of the first importance, in a region noted for its low temperatures and ice gorges, to anticipate such conditions by preparations that would divert the flow of sheet ice and prevent the entrance or formation of frazil and anchor ice at or near the water-inlet.

An examination of the experiences at Niagara Falls, in Switzerland and elsewhere in avoiding or dealing with river ice in its effect upon hydraulic uses, indicated that the question was of serious import and the solution of the problem involved in the use of large units of power was essential to continuity of power production and transmission.

ICE PROBLEMS INCREASE
WITH INCREASE OF POWER PRODUCED

It is clear that the early users of Niagara water-power on a small scale were not brought face to face with the ice problem as it confronts the hydro-electric engineer of today. The circular addressed to capitalists and manufacturers by Augustus Porter in 1847 describes a large raceway to serve as a navigable canal, commencing at a point on the shore of the river where the water is deep and navigable, above the Great Falls, of sufficient capacity to afford water-power for at least *sixty run*[1] *of millstone.* The assurance was given that the

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[1] See Appendix H, Volume II.

Niagara River, at the point where the raceway or canal is supplied, now known as Port Day, *would be entirely free from obstruction by ice.*

Considering that "sixty run of millstone," as operated seventy-five years ago, is estimated to have required 2000 horse-power, it may well have been that its equivalent of 500 cubic feet per second would have had little influence as a draft upon the rapidly moving stream of deep water from which the raceway drew its water supply, and that such supply would have been comparatively free from the floating ice that was rushing towards the Great Falls. The raceway to the miller at Niagara probably had, at that period, a quiet surface on which a protecting sheet of surface ice would have formed. This would have diverted the passing ice floes as a barrier and allowed the water to flow to its use "entirely free from obstruction by ice."

The same optimism appears in the prospectus of the Niagara Falls Hydraulic Company, issued in 1853, which states that "the anchor ice, which in winter chokes the 'race' so as to impede the machinery for weeks, can never form in the proposed canal," and quotes the report of its engineers as follows:

> The ice in this vicinity rarely forms during a winter over from eight inches to one foot in thickness; a full and uniform supply of water for the canal may therefore at all times be relied upon with certainty.

The prospectus of the Niagara River Hydraulic Tunnel, Power and Sewer Company, entitled *Water Power at Niagara Falls,* editions of 1886 and 1888, makes no reference to river ice, and uses the phrase, "nothing to interrupt the steady flow." Thomas Evershed, division engineer of New York State Canals, states in his report upon this project in considering machinery, "that if any stoppage occurred it would not be the fault of the ever-ready river."

ICE FLOES

When, however, the intake of the two power-houses of The Niagara Falls Power Company was called upon to provide in mid-winter the water necessary to operate at full load its water-wheels of 100,000 horse-power capacity, the flow of water through the turbines was at the rate of 9000 cubic feet per second, the velocity of water when entering the intake was about 4 feet per second, and the surface of the water at the inland end of the inlet-canal, when entirely free of ice, was about 0.5 foot lower than at the entrance. The suction, or drawing power, of this current at the entrance to the inlet-canal was sufficient to divert floating ice from its natural course down the river, thus causing masses of ice to accumulate and partially shut off, or dam, the entrance of the inlet, thereby creating a substantial difference in level between the water surfaces in the river and in the canal. This condition produced enormous pressure on the ice masses at the entrance to the inlet-canal, which was greatly increased at times by the strong winds that blow down the river and across from the Canadian side. Hence it is readily understood how it became necessary to provide defensive works of wide extent and great strength, at large expense to establish, and of no small annual expenditure to maintain, to prevent the ice masses from being forced, by southwesterly gales and drawn by the wheel-pit current, into the inlet-canal, filling the same and shutting off the water from entering the turbines.

Southwesterly gales bring out of Lake Erie vast quantities of ice, that often covers the entire surface of the river above Goat Island. Under the influence of the prevailing southwesterly winds, most of the ice takes the channel on the American side of Grand Island and passes the power company's land in an ice stream varying in width up to several hundred feet. The ice sweeps along the 2 miles of river frontage, owned by The Niagara Falls Power Company, with almost irresistible force, often changing its point of attack as the winds and currents vary, and always an impending danger to the industries dependent upon a continuous supply of water as the primary source of their mechanical power.

Northerly and easterly winds send the ice stream towards the Canadian shore, and are accompanied by low stages of the river, as the wind pressure drives the lake water from its outlet in the Niagara River at Buffalo.

ICE GORGES

The effect of wind and ice upon the flow of water in the river is illustrated by the[1] conditions that prevailed on the 31st of March, 1848, as described by Peter A. Porter in his publication entitled *Goat Island, 1900*, as follows:

> For that day only, persons walked in the bed of the rocky channel of the American rapids between Goat Island and the mainland and from Goat Island out in the bed of the main channel towards Canada. But the river was not ice bound; its flow was diminished, not entirely cut off, its supply at Lake Erie having been temporarily blocked. Lake Erie was then full of floating ice, crowding to its outlet, the source of the Niagara River. During the previous afternoon a strong northeast wind had driven the ice back into the lake. During the night the wind veered suddenly and blew a gale from the West. This forced the ice floe sharply, in a mass, into the narrow channel or source of the river, quickly blocked it up, and the still advancing ice sealed up this source with a temporary barrier, pushed some feet into the air. It did not take long for the water north of this barrier to drain off, and in the morning, the Niagara River, as men knew it, "was not." The American Falls were dry. The Canadian Falls were a mere shadow of their former selves, a few threads or streams of water only falling over the edge. People, fearful every moment of an onrush of water from upstream, walked in the channels, where, up to that time, the foot of man had never trod, and where it has never trod since.

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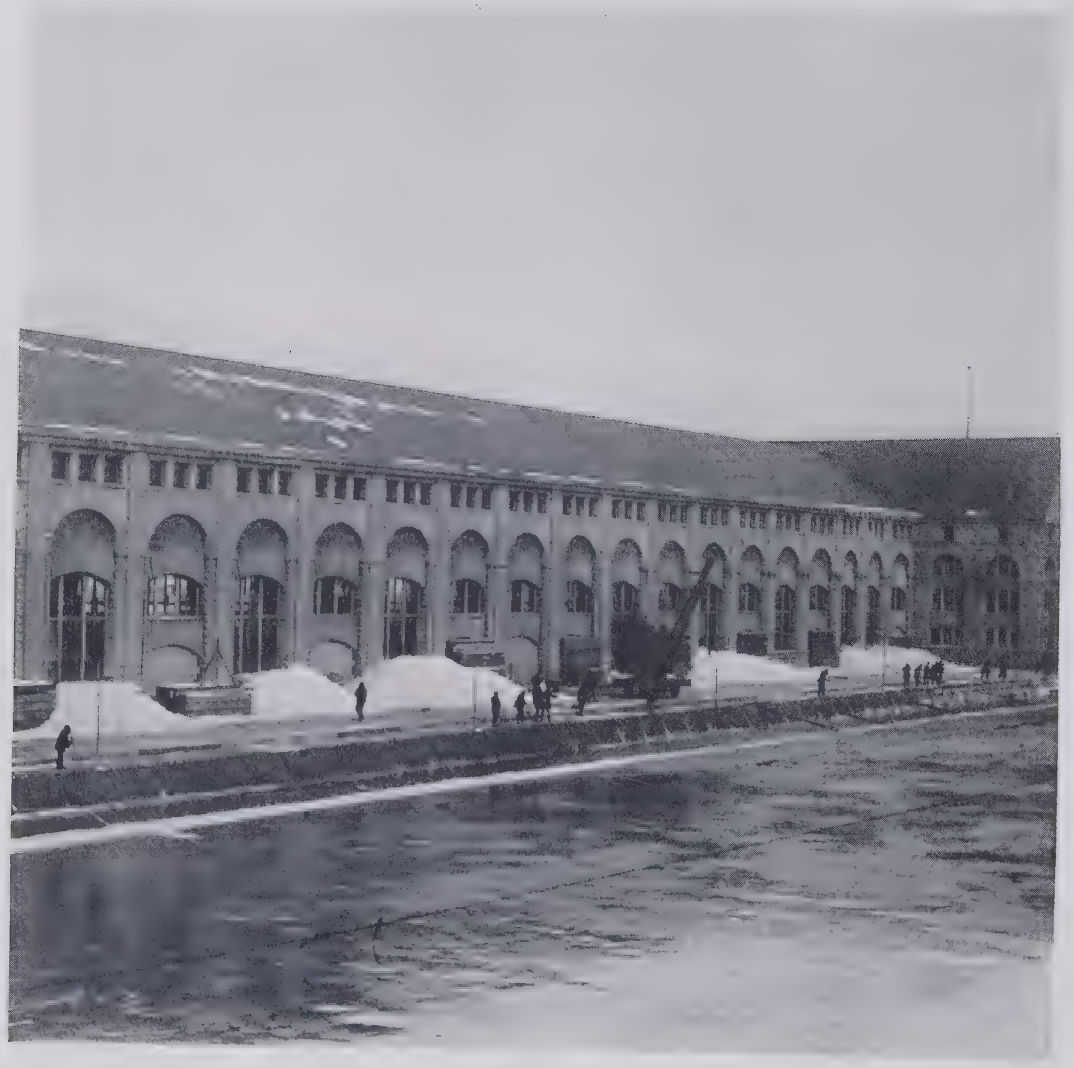
[1] See Appendix F, Volume I.

The roar of Niagara was reduced to a moan; the spray, and therefore, the rainbows disappeared. All day this phenomenon lasted, but by night the sun's rays and the pressure of Lake Erie's waters had made inroads on the icy dam, and during the night the barrier was swept away. By the next morning the river again rushed by in its might, and its roar once more proclaimed that Niagara had resumed its sway.

In a more recent winter of severity, when ice was unusually plentiful and packed the gorge immediately below the falls, the river flow was impeded.



Raking Anchor Ice from Racks, Power-house Number One. Ice Piled Along the Wall Was Taken from Intakes Inside and Thrown Out of the Windows

The rushing waters continued to fall over the great natural dam, but they did not find the usual outlet toward Lake Ontario and consequently "backed up" in the great pool below the falls, and packed with ice the power-house of the Ontario Power Company located at the foot of the Canadian bluff near the falls.

ICE TERMINOLOGY

The terminology of ice formations has not been clearly defined. Some confusion has arisen from the literature upon the subject, wherein, for instance, the terms anchor ice and frazil ice have been used synonymously. A well-known scientist is reported to have explained regarding frazil that it was supposed to be the product of currents of water passing over and disintegrating solid anchor ice, exposing its "bones," just as a rock is worn into irregular forms by the removal of its softer parts. Such opinions as these, however, are now giving way under the critical observations that have been made of recent years, and the true origin of anchor and frazil ice is now better understood.

The various forms of ice known to be dangerous to hydraulic installations have been described as follows:

> Surface, or sheet, ice forms over the surface of quiet lakes or rivers, and is desirable or not, depending on the conditions.
>
> Anchor ice, or ground ice, is the most interesting from the fact that it grows along the bed of a river not protected by surface ice and often causes considerable inconvenience when it rises in great masses, carrying up with it boulders and stones of considerable size. Anchor ice is formed, in the first instance, by radiation of heat during a cold clear night, but increases to great depths by entangling and freezing large quantities of the frazil ice carried down by the shifting currents.
>
> Dr. Howard T. Barnes.
>
> Spicular or frazil ice as it is called in Canada, is formed in the water where surface agitation in turbulent rivers in winter lowers the temperature but prevents the formation of surface ice. It is a "dust of ice" which permeates the water and does not for the moment interfere with its flowing, but whenever this comes in contact with the metal of the water-wheels, no matter what may be the rapidity of the current, there is a rapid and almost instantaneous accumulation in the wheel that entirely fills it and stops the action.
>
> Dr. Coleman Sellers.

DEFENSIVE MEASURES

The study of local conditions at Niagara in 1888 showed that the proposed plan for a long tunnel and short forebays and turbine inlets would concentrate ice troubles in the latter comparatively small fields, where, it was claimed, they should be easily observed and overcome.

Clemens Herschel, the member of the board of engineers of The Niagara Falls Power Company most familiar with hydraulic problems, advised the company of his experiences and recommended details of construction he then considered most likely to protect its interests, from the damage that would result from a stoppage of operations by ice. In the original plans for the plant of The Niagara Falls Power Company an ice-run or shaft was considered to take ice from the inlet-canal near its upstream end. This was not built until after the first winter of operation, 1895–1896, during which the velocity of the water in the canal was inconsiderable, as only two turbine units of 5000 horsepower each were in use. The experience at that period showed that greater precautions against ice interference should be taken before additional power units were started in winter operation.

Mr. Herschel pointed out, in later consideration of this subject, the possibility of using heat, from steam or electricity, in the inlet racks, to prevent the adherence of anchor ice. Rack bars of tubes for the admission of steam, he stated, had been tried, but without success, and no economical heating method had yet been devised. He recommended the use of a series of wicket gates in the inlet racks, which could be reversed to clear their bars from ice and which could be left open in emergencies.

Mr. Herschel then stated:

> The situation will probably be much improved by the construction of the Canadian plant. It is unlikely that either anchor ice or shell ice will act simultaneously to an equal degree to the detriment of the operation of the works on both sides of the river. With the precautionary works above recommended in use on both sides of the river, and the two power-plants connected electrically, it should be possible to keep at least a large part of the power of both plants in operation at any and at all times.

In the first winter of operation, the inlet to each of the two turbines was guarded by a grille of vertical steel bars set in the plane of the canal wall at the inlet entrance. On the first cold night after the temperature of the water had been lowered to the freezing point, frazil built up on the submerged steel bars of these gratings and in a short time formed water-tight barriers that shut off the water from the turbines and closed down the plant.

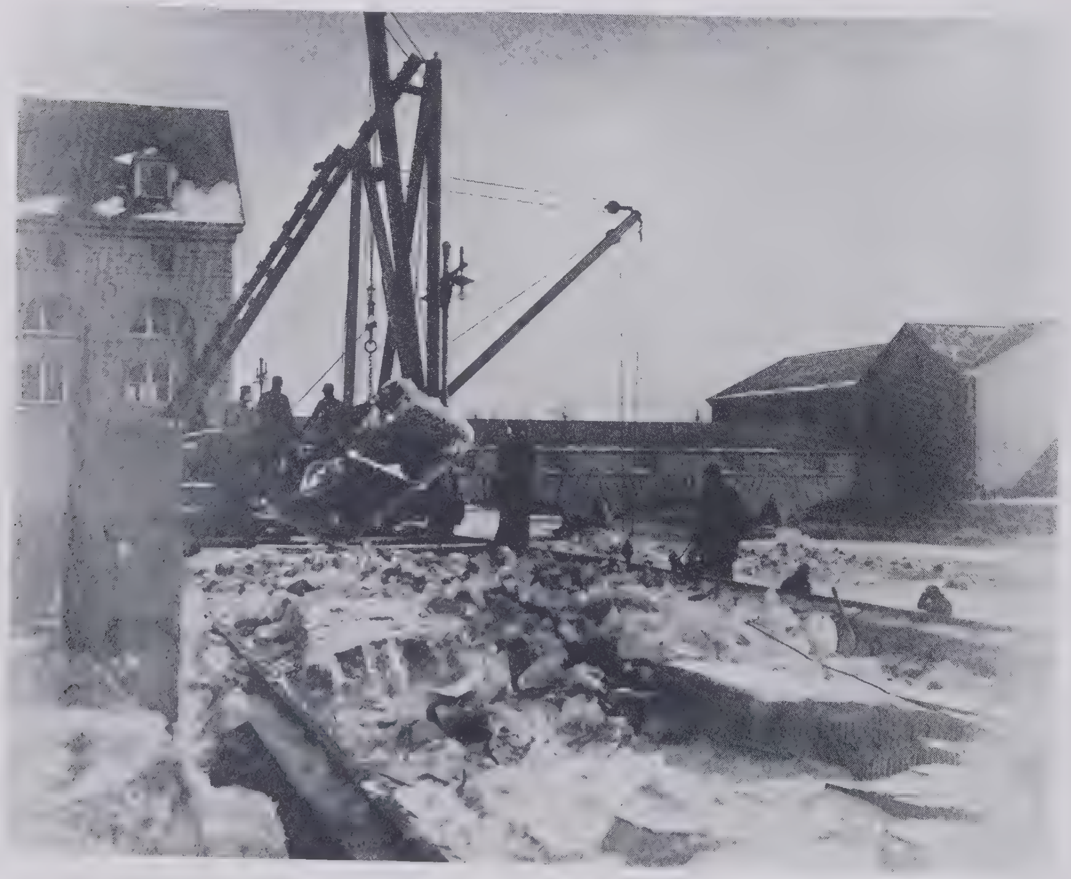
The quick remedy was to remove the steel gratings and the plant was operated without them through the remainder of the ice season. Later a continuous rack of steel bars was constructed in the canal parallel with the wheelpit. The foot of the rack was placed 12 feet and the top 5 feet from the canal wall. The slope thus given made it easier to remove drift material from the rack. With this construction the rack area was not limited to the cross-sectional area of the turbine inlets. The cross-section of the stream flowing through the grating being enlarged, the velocity was less and the removal of floating material was thereby further facilitated. The continuous rack was made with submerged sections removable, and experience established the continuing necessity of removing the gratings during the winter season. Without perceptible effect on output or equipment the turbines will pass large quantities of slush and solid ice blocks of considerable size, which if obstructed by gratings would form an ice dam shutting off water from the inlets.

During the first three winters, with not over three units of 5000 horse-power each in operation and very low velocity in the canal, the ice problem was satisfactorily solved by removing sections of the rack during periods when frazil appeared in quantities. The velocity of water in the canal was not sufficient to prevent the formation of solid ice and in cold weather the surface was covered with a sheet joining the ice field extending out into the river. This barrier of solid ice was a protection against all forms of ice floating down the river. The water passages under it at all stages of the river had ample capacity to supply without appreciable loss of head the requirements of the first three units.

ICE VERSUS QUANTITY POWER PRODUCTION

In the winter of 1898–1899, eight power units, 40,000 horse-power capacity, were in operation, and the water drawn more than doubled, but the velocity in the canal was still low enough to permit surface ice to form, and sections of the rack were taken out as usual. Here again, as from the inception of the central station project, the directors of the company were impressed with the inevitable result of dealing in quantities far beyond any heretofore used in such operations—unexpected and novel experiences, impossible to foresee and difficult to control.

The insufficiency of protection from ice floes was, however, impressively demonstrated in the experiences of that winter. Early in the morning of February 8, 1899, the water level in the canal suddenly fell several feet. The ice sheet, 18 inches thick, left without support, broke up into great fragments, many of which were drawn flatwise across the rack openings, reducing still further the diminished supply of water to the turbines. Broken ice and slush packed the wheel-cases of the turbines and reduced their output, in some instances blocking them entirely. It clogged up the ports through which water pressure was transmitted to the so-called balance pistons by means of which the weight of the revolving parts of the turbines and generators was supported by hydrostatic pressure. Upon removal of this upward pressure the entire weight was imposed on the groove and collar thrust bearings, designed to carry but a very small fraction of such a load. The thrust bearings of four units were burned out almost simultaneously, and these units were out of commission for several days to undergo the tedious process of rebabbitting bearings and scraping them to a fit. The dropping of the load restored the normal level in the canal, but when the load was resumed further trouble developed due to low water and clogging of wheel-cases with ice. Investigation of the ice field in the river outside of the canal disclosed the fact that the entire field was underlaid with slush extending to the bottom of the river, and that the water passages through this mass were insufficient to supply the demand of the turbines. Thereupon a channel about 50 feet wide was cut through the ice field for a distance of several hundred feet from the boom at the head of the inlet. With some difficulty this channel was kept open for the remainder of the winter. The ice formed in the inlet, and that contributed by the river and by the cutting of the channel, was disposed of by the laborous processes



Ice Difficult to Lift from the Canal by Slow, Laborious, Hand-operated Derricks Clogged the Turbines, Necessitating Prolonged Stoppages for Cleaning of working the slush and small fragments gradually through the turbines and lifting large pieces of solid ice from the canal by means of hand-operated derricks mounted on a track running along the platform between the canal and the power-house wall.

Timber Cribs and Booms Extending Downstream from End of Dike, and in Toward the Shore Below Canal Entrance, Showing Effectiveness of This Construction in Keeping Ice Out of the Canal

DREDGING CHANNEL INTO RIVER BED

To overcome the obstacles rendering difficult the entrance to the canal, in the summer of 1899, the river bed was dredged to make a channel 16 feet deep and 250 feet wide extending out into the river for a distance of 400 feet. Experience with ice during the ensuing winter, 1899–1900, led to further dredging in the summer of 1900. A channel 16 feet deep and 80 feet wide was excavated for a distance of 250 feet beyond the end of the channel previously constructed, i. e., to a distance of approximately 650 feet from the boom at the head of the canal. Furthermore, the construction of a dike running from the lower end of Grass Island to the mainland was undertaken upon the theory that ice contributed to the canal by the Grass Island channel would be shut off and that keeping open the channel through the ice from the main river would be facilitated by increasing the velocity therein. This work was begun in the late fall and was carried on through the winter under the direction of Philip P. Barton, superintendent of the operating department of the company, whose resourcefulness was of much value in overcoming the ice difficulties. Units Numbers 9 and 10 were started in the spring of 1900.

Removing Ice from Canal in 1902

The winter of 1900–1901 was mild and gave comparatively little ice trouble. The chief source of embarrassment was the lack of facilities for handling ice in the inlet.

In the summer of 1901, the 16-foot channel, dredged in the preceding summer, was widened to 250 feet, completing a channel 250 feet wide extending into the river for a distance of nearly 700 feet from the boom at the head of the canal. The dike was completed to Grass Island, and as its construction offered a cheap and convenient means of disposing of rock from Wheel-pit Number Two, then being excavated, the dike was extended out into the river for a distance of approximately 600 feet beyond Grass Island, but curving downstream at its outer end.

PIERS AND BOOMS

The winter of 1901–1902 brought prolonged cold weather and many heavy snowstorms. Almost continuously during February there were interruptions of service and reductions of load due to ice. Six units were put out of commission in this period by damaged thrust bearings, several of which were cut repeatedly. Two steam cranes were employed to hoist ice from the canal and by the end of February ice was piled high along railroad tracks in the vicinity of the power-house.

FIGHTING ICE IN CANAL IN 1902

Much of this serious ice trouble was attributed to the extension of the Grass Island dike, which determined the limit of the field of surface ice in the river. This extension was accordingly removed the following summer. The boom at the head of the canal, a solid timber structure about 5 feet wide that rested sidewards against the upstream sides of four structural steel piers, having capsized owing to the increased velocity of water in the canal, was taken away. In lieu thereof the construction of a much longer boom supported by cribwork piers extending downstream from Grass Island was undertaken, but was not completed until March, 1903. To diminish velocities under this boom the dredged channel was widened at its outer end to the full length of the new boom.

ICE-RUNS INTO MAIN TUNNEL

The completion of the tunnel extension into Wheel-pit Number Two made available two sluiceways, or ice-runs, that had been built during the construction of the tunnel extension by means of which ice could be discharged directly from the canal into the tunnel; one at the north end of the canal, the other about the middle of the east side of the canal at the north end of Power-house Number Two. This power-house was put into operation with the starting of Units Numbers 11, 12 and 13 in 1902, followed by Units Numbers 14 and 15 in January and February, 1903. In the design of the intake of Power-house Number Two improvements suggested by experience with Power-house Number One had been introduced. The intake racks were inclosed within the power-house structure, water being admitted to them through submerged arches in the outer wall. The covered forebay was traversed by a small electric crane used for removing sections of rack specially designed to facilitate this operation. These features of the construction of Power-house Number Two and its location relative to that of Power-house Number One have freed it from many of the ice onslaughts to which Power-house Number One has been subjected, and the adoption in the new plant of improved thrust bearings capable of sustaining the entire weight of the revolving parts of the generating units eliminated the thrust-bearing troubles encountered in Power-house Number One.

Dynamiting Channel Through Ice Field to Canal Entrance, 1903

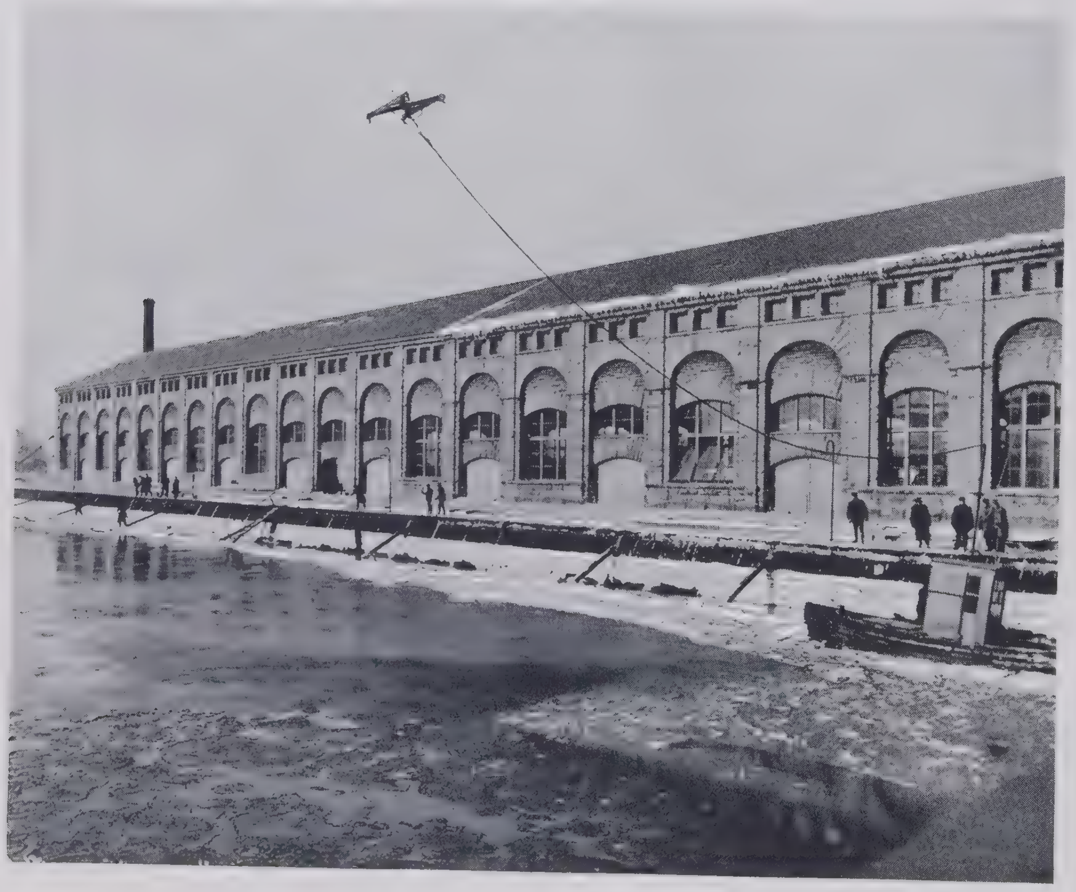
To offset the good effect of these improvements came the increased use of water and higher velocities due to the operation of the new units and the increased output of the plant. Moreover, until March the protection against river ice was impaired by the non-completion of the outer boom.

Much had been expected of the sluiceways, but the first heavy run of slush demonstrated that the surface current towards them, even with the sluice gates wide open, was not appreciable a few feet away. Ice could seemingly not be induced to enter the sluiceways. After a number of unsuccessful expedients were tried, a tug was pressed into service. It was observed that when a stern line from the tug was made fast to a snubbing post while the propeller was driven at a moderate speed ahead, a powerful surface current was created that was most effective in driving ice into the sluiceway. Furthermore, the tug readily pushed through and broke up great masses of ice. With this assistance a canal full of ice could be disposed of in a very short time. So successful was this expedient that two steam-driven tugs became a permanent part of the equipment. In 1904, one of them was replaced by an electrically

Steam Tug and Electric Tug Driving Ice into the Spillway driven tug supplied with motive power through a double trolley circuit suspended longitudinally over the canal.

ICE CONTEST CONTINUED

The winter of 1903–1904 was a very severe one. Thrust bearings on all except two of the generating units in Power-house Number One were damaged,



Electrically Driven Tug Forcing Ice into Spillway at Lower End of Canal. Lowering of Water by Ice Jam at Entrance to Canal Is Shown by Ice-line on the Racks Indicating Normal Water Level

some of them repeatedly. On the other hand, the minimum load at times of reduction was much larger than in any preceding winter, and with the exception of one brief reduction the long-distance load was not affected by ice, although this load was far greater than ever before. The report of the operating superintendent for that period states:

> Consideration of the winter's experience confirms my belief that the ice problem has been practically solved for the load conditions of two years ago, on the basis of which recommendations were made for improvements, in protection against ice, that now exist. As was anticipated, new load conditions have developed further difficulties, which demand the construction of additional safeguards, and obviously the same process must continue until the output of the plant has reached its limit.

During the summer of 1904, a channel 30 feet wide was dredged from the canal entrance out into the river to a point approximately 800 feet beyond the new boom and two barrier cribs were placed. Five cribs which had been overturned during the previous winter by the shove of ice floes, were replaced by new ones of larger size and improved construction.

Although the ensuing winter, 1904–1905, was by no means abnormally mild, there were few interruptions of service and almost no damage to thrust bearings. This was attributed mainly to the dredging done in the preceding fall. It was easy to open and maintain in the dredged channel a passage through the ice field, and water flowing through this cut in the river bed maintained throughout the winter favorable water level conditions in the canal.

DREDGING, BOOMS AND VIGILANCE SUCCEED

In the spring of 1905, the dredging was completed by extending the 16-foot channel to a distance of more than 1000 feet from the outer boom and making it 100 feet wide. Three additional barrier cribs were placed above this channel.

The ice history of subsequent winters has varied in detail with the weather conditions, but a typical experience may be described as follows: The first run of ice down the river arrives usually between December 15th and January 1st. Much of it passes under the outer boom into the canal, where the tugs usually are able to dispose of it through the sluiceways without serious difficulty. An ice barrier builds up gradually at the outer boom until it reaches a width of 1000 to 1500 feet out to the open water of the river. As soon as the ice becomes stiff enough to support workmen, a channel is cut through it for a distance of several hundred feet. At the first evidence of low water in the canal, dynamite is used to break off the outer edge of the ice field and the channel through the ice field is enlarged. This procedure is maintained until the end of February. During March and April, the ice field breaks up, but is held against the boom by the draft of water into the canal and is maintained or renewed by continual accretions of lake ice floating down the river. On one or two occasions sections of the boom have broken and allowed the canal to fill with broken ice, which had to be disposed of through the sluiceways. As this has occurred in the spring in comparatively warm weather, the ice was easily handled and caused only temporary inconvenience for a few hours.

The replacing of the original ten turbines in Power-house Number One with units equipped with improved thrust bearings, designed to carry the entire weight of the revolving parts, was begun in 1909 and completed in 1912. This eliminated the vexatious thrust-bearing troubles so prevalent in earlier winters. Both power-houses now withstand ice attacks with no greater inconvenience than a partial reduction of load for a few hours while the canal is being cleared of ice through the sluiceways, of which three are now available. The interconnections, by transmission lines, between the two American plants and the Canadian plant have been of great assistance in maintaining uninterrupted continuity of electric service to public utilities and to customers whose

On a Few Occasions Ice Broke Through the Boom with the Result Shown Here. This Ice Was Driven Down the Spillway and Cleared Away in a Few Hours by the Tugs processes would be seriously dislocated or whose plants would be damaged by even temporary failure of power service.

The results of the expedients and improvements described in the foregoing paragraphs may be indicated by the record of the winter of 1917–1918, a winter displaying more than the average quota of cold and stormy weather, and more than the usual quantity of ice in its varied forms. The average output of the plant for the four winter months was over ninety-five per cent of the possible output at maximum rated capacity. The reduced output due to all causes, including maintenance of equipment, non-use by customers, customers' load factor, etc., and ice, was less than five per cent. *The loss due to ice alone was reduced to an almost negligible quantity.*

The winter months of early operation were periods of great anxiety to the operating officials and their staff, until experience had shown what would greatly modify if not entirely prevent ice clogging of the wheels.

The defensive measures taken were expensive and unexpected but they were valuable as experience and permanently useful, such as dredged channels, established ice booms in the river, ice-rims from inlet to tunnel, and thrust-bearings that would carry the full weight of the turbo-electric machines in case of need.

Conditions were still further improved in 1918 by the intake channel 20 feet deep and 200 feet wide dredged by the Hydraulic Power Company from Port Day upstream to a point several hundred feet above the dredged channel of The Niagara Falls Power Company, and by the long boom constructed by that company for the purpose of diverting ice from the American shore to the Canadian channel. Commencing at the intersection of this channel with the ice line, a series of piers consisting of steel sheetpile cylinders filled with concrete were built running upstream in the general direction of the ice line, but gradually working in toward the shore. Floating booms of truss frames were placed from pier to pier. About half way between this row of piers and the shore, another row was placed, extending in the same direction and supporting floating booms in the same manner as the outer row. In operation, these booms have kept out the ice floating down the river and what small amounts actually formed inside the booms have been broken up from time to time in small quantities by the company's ice-breaking tugs and allowed to flow down to the canal where it was disposed of through the spillway gates. As a result of improvements at the American plant prior to 1917, the reductions of load at Power-houses Numbers One and Two by reason of ice have not been frequent or of importance.

CANADIAN PLANT

The experience of the Canadian Niagara Power Company with ice may be described briefly as follows:

The location of the Canadian plant at a point towards which the river current sets strongly resulted in a rather serious ice problem. The construction of intake racks in a covered forebay, to which water is admitted through submerged arches, is similar to that of Power-house Number Two of the American plant. Sluiceways were provided at the downstream end of the covered forebay and at the downstream end of the outer forebay, discharging into a channel leading back to the river at a point below the main intake. The head of the intake was guarded by a screen of steel bars mounted on stone piers. The screen was submerged to a depth of 4 or 5 feet below normal water level, but proved to be quite ineffective in excluding from the forebay either

Ice Field Seen from End of Shortened Dike. Cribs and Booms Extending Downstream Prevented This Ice from Entering Canal (1907) solid ice or slush. Ice entered beneath it in quantities that could not be discharged through the sluiceways with the help of a powerful electrically driven tug installed in the outer forebay. Repeatedly in each winter wheel-cases and penstocks became clogged with ice and serious reductions in load had to be made for periods of many hours. As additional units were put into service, the necessity of remedying these conditions became more and more pressing, and in 1916, a radical reconstruction of the intake was undertaken. This work contemplated

1. Relocating and enlarging the sluiceway in the outer forebay;
2. Increasing the depth of the outer intake from 12 feet to approximately 20 feet;
3. Constructing an improved ice shield outside of the original ice rack, at a point where the river current would be more helpful in sweeping ice past the intake. This ice shield consists of a series of concrete piers with grooves for stop-logs to close the upper portions of the openings between piers, permitting water to be drawn from the bottom of the river, where it is comparatively free from ice.

All of these improvements were completed in 1918, and the reductions of load on account of ice at the Canadian plant became of comparatively insignificant importance until the severe winter of 1919–1920, when it became evident that the ice problem of the Canadian Niagara plant had not been fully solved. The submerged weir remained in an experimental stage. Although cribs and diverting booms have been established to deflect the current ice, yet when the wind blows towards the Canadian shore the ice from the large Canadian owned power-plants above the location of the Canadian Niagara Power Company (American) is thrust against its inlets, its forebay becomes filled and its waters clogged with ice, that in severe weather interferes frequently, although temporarily, with the operation of this plant.

CONSOLIDATION OF AMERICAN COMPANIES IN 1918

John L. Harper[1] stated that "at the present time (1921) no changes are contemplated in regard to this Canadian intake for the reason that any adequate ice disposal system would require such an expenditure of money that the ordinary diminutions of power can be accepted with less loss than would be imposed upon the system in carrying continuously (paying the interest upon) the expense of an adequate ice disposal system for this plant."

[1] Vice-president and Chief Engineer of The Niagara Falls Power Company, MCMXVIII.

The consolidation of the American power companies in 1918 permitted a systematic co-operation for ice defense that has proved advantageous to the united plants.

Although the winter of 1919–1920 was one of the most severe ever experienced in that section of the country, Mr. Harper reported that the completed system of cribs and booms operated so successfully that no diminution of the development of power was caused by ice obstruction on the American side.

Removing Eel Grass from Intake Racks, Power-house Number One

HEAT APPLICATIONS PREVENT FRAZIL

The literature upon the subject of the formation of ice as an interference with the operations of hydraulic plants was meager in 1886 and 1889 when this subject was under investigation. Personal experiences with water-wheels or turbines of comparatively small power, in northern climates, in this country and abroad, were the principal sources of information for guidance in the plans for Niagara.

It was not until 1906 that comprehensive and scientific work upon this subject appeared. This was entitled *Ice Formation,* by Howard T. Barnes, and is generally recognized as authoritative upon the subject. The scientific principles established by the researches recorded in this volume stimulated observation and experimentation by hydraulic engineers and operating managers, who informed their associates and the public of their experiences, by reports and addresses, so that by 1920 there was a fund of knowledge that has led to methods which, Dr. Barnes anticipated, "will so temper the effects of ice in our northern rivers as to render them no longer a bar to the full development and utilization of our vast water-powers," and he hoped "that it will be no longer necessary for water-power users to view with alarm the advent of cold weather with its consequent production of frazil."

Murphy Experiment in Formation of Frazil

The simple but effective remedies for the difficulties caused by frazil and anchor ice at hydraulic plants, suggested and demonstrated, 1908–1920, by John Murphy,[1] of Ottawa, Canada, have been helpful to many students of this subject, especially to the operating managers of these Niagara power companies. He states that by the simple opening of a steam valve and the application of sufficient heat to the wheel-case to raise its temperature a small fraction of a degree above freezing point, a set of water-wheels can be cleared of frazil in a few minutes, and by the earlier application of a little heat to the wheel-case frazil will not accumulate in it at all, and the plant can be kept in uninterrupted operation.

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[1] Electrical Engineer, Department of Railways and Canals, Railway Commissioner of Canada, and Consulting Engineer, Ottawa.

In his paper entitled ***Frazil and Anchor Ice,*** read at Montreal in September, 1907, at the annual convention of the Canadian Electrical Association, Mr. Murphy stated that "no hydraulic plant need now be tied up by frazil if the simple remedy of applying a moderate amount of heat to the vulnerable parts of the equipment be resorted to."

Niagara Falls in the Winter of 1919–1920

The most vulnerable points on hydraulic power-plants, Mr. Murphy states, are where the usual effect of frazil is to block up the racks, tie up the gate mechanism and reduce the output of the water-wheels or shut them down altogether.

While the application of a small quantity of heat to the metals composing the vitalizing mechanisms from the racks to the water-wheels is a simple and economical process, as herein explained, for avoiding difficulties from frazil ice, there is also the broader problem, requiring in its solution large expenditures of money, for permanent establishments of channels, cribs, booms and their maintenance, to divert the currents carrying the floating ice and to prevent any hindrance to the flow of water in the channels leading to the canal, forebay and inlets of the power-plant.

At the time that the first central power station was built at Niagara, the natural formation of ice was understood mainly in its simpler forms. No such quantities of water had been diverted and utilized before, nor developed in such large units of power and in such small areas.

Quantity production of power by hydraulic methods for the first time revealed ice as an arch-enemy in new forms not then fully understood.

Novel appliances and new arts were necessary to control and measure this great power. This was one of the serious problems of the pioneers in central station hydraulic power production in northern climates on a large scale for long-distance transmission and distribution of electricity as light and power.

Solutions were developed from experience in the new plants at Niagara and by other workers following in hydraulic operations under somewhat simpler conditions of temperature and use, so that, as Dr. Barnes hoped in 1906, it may now indeed be asserted that it is "no longer necessary for water-power users to view with alarm the advent of cold weather with its consequent production of frazil."

EULOGIUM

WRITTEN AFTER VISITING THE WORKS OF
THE NIAGARA FALLS POWER COMPANY
IN 1907 BY

ROYAL CORTISSOZ

Member of the American Academy
of Arts and Letters
Art Critic and Author

BEING *utterly ignorant of these things, I won't commit the impertinence of pretending to appreciate the genius embodied in those colossal fabrics. All I can tell you is that they made me feel as though I was looking on while some unthinkable Olympian went gloriously mad, in a kind of divine frenzy, and expressed himself in terms raising the art of the Egyptian temples to a higher power, giving to things of overwhelming bulk an immeasurable life and purpose, and somehow putting over them a glamour of the subtlest delicacy and charm. It was like a fairyland created for the pranks of the high gods. It was like a force of Nature tamed and held by a silken thread. I won't say it was like the most wonderful thing in the world. It is itself the most wonderful thing in the world.*

THE ART OF ELECTRIC POWER DEVELOPMENT AND TRANSMISSION, 1890–1893

CHAPTER XXI

Sir C. William Siemens, F.R.S., D.C.L., LL.D.
1823–1883
English Engineer and Inventor

THE ART OF ELECTRIC POWER DEVELOPMENT AND TRANSMISSION, 1890–1893

CHAPTER XXI

PREDICTIONS IN THE SEVENTIES

IT is difficult in these days to appreciate adequately the progress in the use of electricity for light and power during the past forty or fifty years. This progress is hard to comprehend whether the changes in apparatus and physical development be considered, or the quantity used, or the service rendered in doing the work of the world and ameliorating the conditions of daily life.

The influence of the falls of Niagara upon the minds of scientists, particularly those of practical as well as theoretical achievement, stimulated inventions for the utilization of the colossal mechanical power available for the development of a source of wealth to the nation. This may be better appreciated by several illustrations of such inspiration of scientific observers from the banks of the great cataract.

Sir William Siemens, of London, visited Niagara in 1876. His active life was replete with economic discoveries and their application. In March, 1877, in describing the transmission of water-power, he used the following statement in his presidential address before the Iron and Steel Institute of Great Britain:

> Time will probably reveal to us effectual means of carrying power to great distances, but I cannot refrain from alluding to one which is, in my opinion, worthy of consideration, namely the electrical conductor. Suppose water-power be employed to give motion to a dynamo-electrical machine, a very powerful electrical current will be the result which may be carried to a great distance through a large metallic conductor, and then be made to impart motion to electro-magnetic engines, to ignite the carbon points of electric lamps, or to effect the separation of metals from their combinations. A copper rod 3 inches in diameter would be capable of transmitting 1000 horse-power, a distance of, say, 30 miles, an amount sufficient to supply one quarter of a million candle-power, which would suffice to illuminate a moderately sized town.

It is recorded[1] that "this statement startled the audience considerably; and it is still remembered that, when it was delivered a smile of incredulity was observed to play over the features of many of his hearers."

When giving evidence before an English parliamentary committee in 1879, two years after the startling prediction of Sir William Siemens, Sir William Thomson (afterward Lord Kelvin) stated that the electrical transmission of power was then attracting the attention of electrical engineers, as it had been accomplished in Europe in a small way. He said that he looked forward to the extensive use of Niagara Falls for the production of light and mechanical power over a large area of North America, and that a copper wire half an inch in diameter would transmit 21,000 horse-power from Niagara to Montreal, Boston, New York and Philadelphia.

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[1] Life of Sir William Siemens, by William Pole.

Lord Kelvin[1] often mentioned to his friends and associates in the Niagara Falls power project that his swim in early life from the dock of the Niagara River, immediately below the Great Falls, had baptized him in preparation for his co-operation in the effort to "harness Niagara."

ELECTRICAL SYSTEMS IN USE IN 1890

The state of the art of electric power development in 1890 is of especial interest in the history of The Niagara Falls Power Company as this was the period when the problem of determining whether any method of power transmission was adequate and then of choosing between electrical and non-electrical methods as to which was of outstanding promise. The general status of power transmission at that period is presented in the preliminary reports of Dr. Sellers and others in the fall of 1889, which appear in Volume One, Chapter VIII.

Of the projects presented at that time by the leading engineering talent of the world to the International Niagara Commission, part proposed electrical transmission and part proposed pneumatic or hydraulic or mechanical methods. Electricity had not yet demonstrated its capability to do things on a large scale. The rate of growth in the output of electric power stations has been about one hundred per cent in five years, and counting back at this rate the electrical power in this country in 1890 was only one per cent of what it is today. To have predicted the future would have been more difficult then than it is today to foretell the conditions a generation hence, if a hundred times our present output is brought into service. In fact, the early prediction would have been far more difficult as it was then uncertain whether machines of large size could be safely used. Now it is taken for granted that we can physically do whatever is commercially desired.

The principal electrical "systems" in common use in 1890 which will be explained in some detail were for arc lighting, for incandescent lighting by direct current, for incandescent lighting by alternating current and for street railways and other power purposes.

ARC LIGHTING

Arc lamps, used for street lighting and for large interiors were connected in series and the current passing successively through the lamps was of the same strength in all parts of the circuit. As each lamp added to the voltage of the circuit the number of lamps supplied by an arc lighting machine was limited by the permissible voltage and usually did not exceed 50 or 60 lamps. A city requiring one or two thousand lamps required more than a score of arc machines, driven individually from many small steam engines or by belts from a main shaft which in turn was driven by a belt from a large engine. Practically every city and town had its arc lighting plant ranging from many machines and circuits to a single small machine supplying a few lamps. Direct current was used; there were many different styles of machines and lamps. This lighting had been in use for ten years or more.

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[1] See portrait of Lord Kelvin, Chapter XXVII.

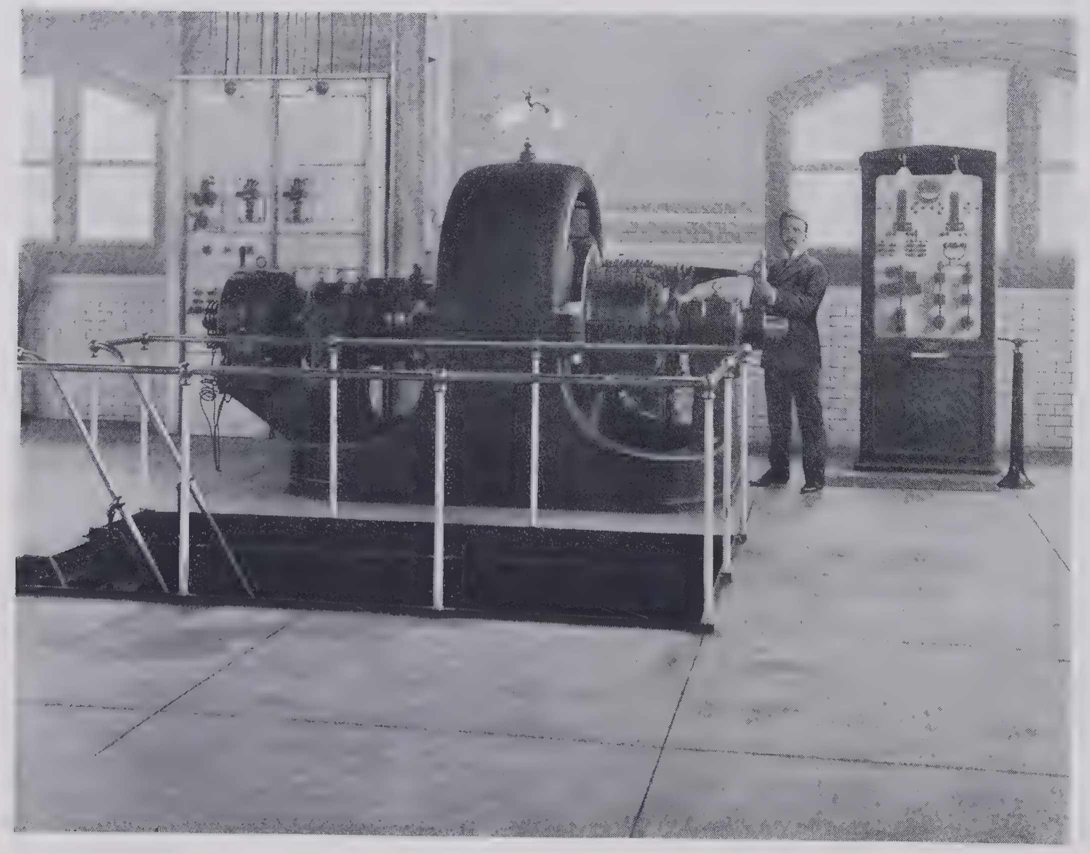
DIRECT-CURRENT INCANDESCENT LIGHTING

The earliest incandescent lighting was supplied by isolated plants in hotels and office buildings, and the first central station for the general distribution and sale of electricity was that of the New York Edison Company, which began operation in September, 1882. Incandescent and arc lighting presented several marked contrasts. Not only were the newly developed incandescent lamps small and suited to general indoor use, but the lamps were connected to the circuit in parallel or multiple instead of the series connection employed in arc lighting. Hence the pressure or voltage between the wires was maintained constant and an increase in the number of lamps was accompanied by an increase in the current, while the arc lighting circuit required an increase in voltage as lamps were added. The low voltage adapted for incandescent lighting was safe for indoor use and the number of lamps on a circuit could be indefinitely increased provided the size of the conductors was made adequate for carrying the greater current.

The introduction of the incandescent lamp and the constant voltage system was followed by the commercial introduction of central stations for supplying current in the cities and principal towns of this country and Europe. But the system had a serious limitation in the short distance to which current could be economically transmitted. The large current required for many lamps required large copper conductors and as both the size and length must be increased when the distance is great it was found that the limit fixed by cost of conductors was a few thousand feet, or about half to three-quarters of a mile, although the arc lighting circuits with their small current and high voltage could be operated over a distance of several miles. No satisfactory method was found, however, for commercially supplying incandescent lamps except within a short radius. The outlying districts of cities with a central plant were without incandescent lighting service.

ALTERNATING-CURRENT INCANDESCENT LIGHTING

The demand for long-distance incandescent lighting was met by the alternating current. A small current at high voltage was carried by a small wire and then changed by a simple and efficient "transformer" to a large current at the low voltage suited for incandescent lamps. The first alternating current central station in this country began operation in November, 1886, in Buffalo. The primary voltage was 1000 volts which enabled service to be supplied at any point within a distance of a few miles. Stations of this kind were installed in many places, resulting in a violent commercial competition to which reference has been made. Greater distances became practicable with the introduction of 2000 volts and in 1890, 4000 volts enabled Portland, Oregon, to be lighted from Willamette Falls, some twelve miles distant.



First Rotary Converter to Supply Direct Current for Street Railway Operation, 1895, Located in Power-house Number One

It appears that the commercial antagonism encountered in introducing the alternating current in America was but a counterpart of the criticism which had occurred in its earlier introduction abroad. In November, 1887, Prof.

George Forbes made the following statement at a meeting of the American Institute of Electrical Engineers:

> The greatest step, it seems, which has been taken in the distribution of electricity since the period when electric lighting took such a start in 1878 was the use of alternating currents with induction apparatus, which was simply achieved by the most indefatigable industry and plucky perseverance against the opinions of everybody who seemed to be capable of giving an opinion. I have never omitted, on any occasion when I had to speak about the distribution of electricity, to express the profound admiration I have had for the energy and pluck which was shown by Messrs. Gaulard and Gibbs in working out that system upon which so much ridicule was cast during the whole time they were making their experiments.

STREET RAILWAYS

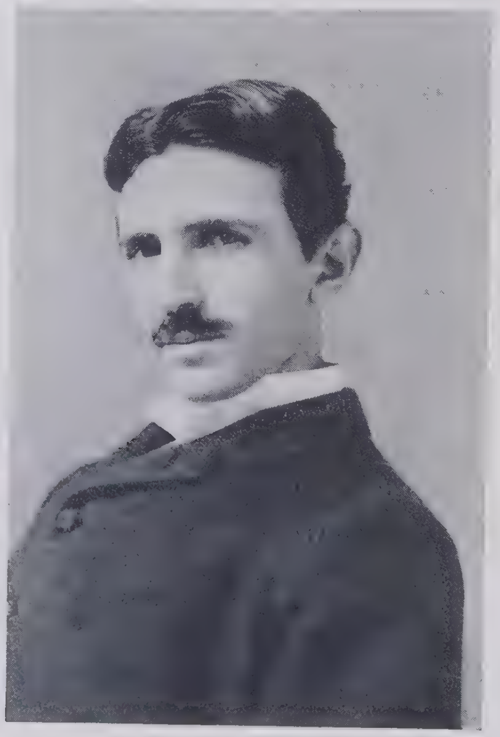
Electric railways had recently passed from the period of the short experimental line with a few cars to the beginning of important systems in larger towns and cities. The 500-volt direct-current trolley then used has persisted with little change in the fundamental elements of its motor and transmission. This voltage permitted the operation of cars for several miles from the power station.

STATUS OF THE ELECTRIC MOTOR

Electric power for motors (other than railway) could not with full satisfaction be supplied in a comprehensive way by any of the foregoing electrical systems in common use in 1890.

The constant current system, such as was used for arc lighting could operate motors but as the motor was connected in a high voltage line it was difficult to insulate it and to make it safe for the attendant. Furthermore, auxiliary control devices were necessary to prevent wide speed variation when the load was changed. This method was employed on a small scale in various transmissions of power by Deprez in France and by others as described in subsequent chapters. Generators and large motors however could be constructed for several thousand volts, and several generators (and likewise several motors) could be operated in series thereby enabling still higher transmission voltages to be employed which were suited for longer distances. The use of a large motor or several motors driving one shaft in a receiving station with skilled attendants obviated the difficulty in the operation of many small motors in different places. In such a receiving station the mechanical power developed could drive the shaft of a mill or it could operate low voltage generators for supplying current for general service. This was the general method proposed by Mr. Edison in 1889 for transmitting power from Niagara Falls to Buffalo. Power could, by this method, be transmitted very considerable distances but it was in general power to a single shaft in a single station. It was not suited for general service for small motors, except through the agency of a generator driven by the motor in the receiving station.

Constant voltage direct-current circuits of 110 or 220 volts for lighting and of 500 volts for electric railways were well suited for supplying current for motor service. In 1890, motors were operated from lighting circuits, for fans, printing presses and small manufacturing purposes. But in general the use was small and incidental to the lighting; the variation of current to motors at starting or due to changing load was apt to cause objectionable variation in the intensity of the illumination from the same circuits. Either 220 (or 250) volt generators and circuits could be used for motors for public service or in factories; 500 volts was regarded as too high for general supply to small motors. These systems were not much used as electric motors were few in



Nikola Tesla, A.I.E.E.
Electrical Engineer

1890; and moreover, they were not suited on account of the low voltage for operation at distances greater than a few thousand feet or a mile or two. They were adapted to local distribution of power, rather than for its long-distance transmission.

Alternating current which made rapid headway for lighting service over longer distances was handicapped in the power field for lack of a motor. There was no satisfactory small motor. A duplicate of the generator could operate as a motor, but it was not self-starting and it required auxiliary devices for bringing it up to speed and for supplying exciting current. The synchronous motor as it was called was suited only to a limited and special field.

A new alternating-current motor and a new alternating-current system had been announced by Nikola Tesla two years earlier, in 1888. His polyphase system involved two or three currents from the same generator, each alternating and in itself corresponding to the ordinary "single-phase current," but the two or three currents followed one another in regular sequence, corresponding to the sequence of the cranks of a two or three-cylinder engine. Very much as the multicylinder engine overcomes the dead points of a single-crank engine so the multiphase or polyphase system produces a rotation which the single-phase system does not. The unique feature of the new system was the induction motor, with no commutator (an essential part of the direct-current motor) and with almost ideal simplicity of construction and operation.

But in 1890 the Tesla motor was still a prophecy rather than a completely demonstrated reality. The immediate demand was for motors to operate from the existing lighting circuits, which were single phase and had a frequency of about 130 cycles per second. Futile attempts were made to modify the motor to meet these conditions. A few installations of induction motors of 2 horse-power and of 5 horse-power were operating coal mining machines from two-phase generators of low frequency near Pittsburgh, and in Europe there was a project for a large Tesla motor and a long-distance transmission for operation at the Frankfort Exposition the following year.

ELECTRIC LIGHT AND RAILWAY PLANTS IN 1890

In 1890 few machines exceeded 100 or 200 horse-power capacity. Sometimes several or all classes of service were supplied from many generators in one power-house but more commonly there were several small stations located at different parts of a city and operated by different companies. Some cities had as many as a dozen or more electric light plants, each supplying its adjacent district. A list of the central stations for electric light and railways in the United States in the latter part of 1890 was compiled and published and is summarized in the following paragraphs from the *Electrical World,* February, 1891:

> In a very comprehensive series of maps recently published in book form by the Thomson-Houston Electric Company some very valuable information is given concerning the location and character of the central station electric light plants and the electric railways of the United States. In the number of electric railways, Massachusetts heads the list with 21, while Utah, Delaware and South Dakota are at the foot with one road each. Of electric railway systems the following tabular list is given; Thomson-Houston, 103; Edison, 83; United Electric Traction, 21; Van Depoele, 8; Rae, 8; Short, 8; Storage, 4; Westinghouse, 3; Bentley-Knight, 1; Underground storage, 1; total 240.
>
> In the number of electric light systems New York State heads the list with 189 central station plants while Arizona is at the end of the list with only two central stations. The systems in use in all the states are divided as follows: Thomson-Houston, 666; Westinghouse, 323; Edison, 202; Brush, 199; Ft. Wayne, 144; American, 67; Western Electric, 53; United States, 51; Schuyler, 49; Heisler, 49; Waterhouse, 41; Ball, 31; Van Depoele, 31; Excelsior, 25; Sperry, 24; National, 16; Remington, 4; Eickemeyer, 2; Hawkeye, 2; Standard, 1; Hochhausen, 1; Knowles, 1; Mayo, 1; Keith, 1; total, 1984. It is stated in the preface to the book that the data contained in the maps have been collected from original sources by a disinterested party.

In this summary practically all of the Westinghouse and a few of the Thomson-Houston lighting systems were alternating current, the Edison stations were direct current for three-wire incandescent service and the remaining stations numbering well over 1000 were practically all for arc lighting.

LONG-DISTANCE TRANSMISSION

The typical city service which has just been described constituted a large proportion of the electrical activity in 1890.

The list of exceptional transmission plants in America begins with the plants at Willamette Falls and at Telluride.

At Willamette Falls generators of 4000 volts supplied current for transmission to Portland, Oregon, a distance of 12 miles. The pressure was reduced by transformers to approximately 1000 volts which was supplied to ordinary lighting circuits, each generator supplying 1250 lamps. This plant began operation in the summer of 1890 and within about a year a total of seven or eight generators were in operation.

In the fall of 1890 a 100 horse-power synchronous motor operated from a single-phase generator of slightly greater rating was supplied for operating a mining plant near Telluride, Colorado. The voltage was 3000 and the distance was 3 miles. Operation began in the following spring. The successful transmission of power at so high a voltage, to so great a distance, for the operation of so large a motor by alternating current which was readily adapted for higher voltage and longer distances, was a notable advance in electrical power development.

Mr. Stanley stated in the electric-lighting convention in Buffalo in 1890:

> That there was no apparatus existing at that time which would be commercially operative to transmit the power from Niagara Falls to Buffalo.
>
> Similar powers have been transmitted, not of the magnitude of the Niagara power-plant, over distances greater than that to be transmitted to Buffalo, but the peculiar feature of the Buffalo-Niagara transmission plant is that the forces coming into play in that plant are so tremendous, as compared with anything that has been done before that the engineering problem has to be solved entirely afresh.

In Europe there was greater activity along the lines of special developments aside from the ordinary lighting plants. In a number of instances power in small amounts was transmitted to considerable distances by direct current in circuits in which the current was constant and the voltage was approximately proportional to the load. The transmissions by Deprez in France and a number of transmissions in Switzerland were of this type. They have been referred to in preceding chapters in the account of the visit of the officers of The Cataract Construction Company in their investigations during 1890. There were also some single-phase synchronous motors in operation, notably two designed by C. E. L. Brown, of 80 horse-power output which were operated at 2000 volts.

INTERNATIONAL NIAGARA COMMISSION

Another significant indication of the state of the art in 1890 is contained in the projects presented by prominent engineers and engineering firms for the transmission and distribution of power at Niagara which were presented to the International Niagara Commission. These are described more fully elsewhere.[1] None of the projects submitted was deemed worthy of a first prize. Of the six electrical proposals four were for direct current and two were for alternating current. One of the direct current proposals contemplated 1250 horse-power generators, giving constant potential for the local distribution in which it was proposed to operate two systems, one 2000 volts three-wire for 1000-volt motors and the other 1000 volts, three-wire for 500-volt motors. For the transmission to Buffalo, it was proposed to employ a constant current of 544 amperes supplied by ten 1600-volt generators in series giving 16,000 volts at full load, which would operate motors connected in the same way in receiving stations in Buffalo where they would, in turn, operate generators supplying constant voltage circuits similar to those proposed for local distribution at Niagara Falls. An alternative arrangement slightly modified these conditions.

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[1] Chapter X, Volume I.

In another direct-current project the dynamos were to be of 2500 horsepower supplying 330 amperes and 5000 volts which was the highest potential proposed. The receiving machines in Buffalo were to be similar to the generators and were to be used for driving low tension dynamos.

One of the alternating current proposals was for single-phase and the other, by Professor Forbes, proposed polyphase currents. All of the proposals seemed rather vague and indefinite, as in fact they were, because they were dealing with magnitudes far beyond anything which had yet been achieved.

"ELECTRIC TRANSMISSION OF ENERGY," GISBERT KAPP

The state of the art of electric transmission at the time the study of the Niagara project was undertaken in the summer of 1889 is presented in *Electric Transmission of Energy* by Gisbert Kapp of London. The preface to the second edition is dated October, 1889. In this book of some 350 pages much attention is given to the underlying principles involved and to the performance of individual machines. A chapter is devoted to the possible applications of electric transmission. Some sentences from this chapter indicate its import.

> Electric transmission has therefore to compete with a host of mechanical devices and it becomes important to compare it with them . . . . Whether electricity is ultimately destined to supersede shafting, pulleys and other gear now commonly used for transmission of energy over short distances is a question which only enthusiasts, or those imperfectly acquainted with the technical part of the subject can be bold enough to answer . . . .
>
> It would seem that long-distance transmission offers a better field for the application of electricity than short-distance transmission. The reason is not that it is easier to transmit energy electrically over longer distances, but that the difficulties of employing purely mechanical means are so great as to make competition easier . . . . There are four systems of importance suitable for long-distance transmission: The electric transmission of energy; the hydraulic transmission of energy; the pneumatic transmission of energy; the transmission of energy by wire rope.

After sixteen pages of comparison of these several methods of transmission the chapter concludes with these paragraphs:

> Summarizing the results detailed in the table, we come to the following conclusions:
>
> 1. It pays to transmit cheap water-power; by wire rope if the distance is less than a mile, and electrically if the distance is a mile or more. This applies to all powers.
>
> 2. It pays to transmit cheap steam-power if the amount of energy required at the receiving station does not exceed 10 horse-power. If the distance is

> less than a mile use wire-rope transmission; for distances of 1 mile and upwards, up to 2 or 3 miles, use electric transmission. Beyond this limit a small local steam or gas engine is preferable.

In the final chapter dealing with installations the following is significant:

> At the present time there are so many electric transmission plants in actual use that the task of choosing one or two for more detailed description becomes a somewhat invidious one . . . . The Maschinenfabrik Oerlikon in Switzerland has not only carried out the largest plants of electric transmission, but has also had some of them investigated by independent authorities, and thus given the scientific world the benefit of their experience . . . . At the present time a slow but sure process of replacement of the wire rope by the electric conductor is going on in Switzerland and neighboring countries where water-power is abundant . . . . The first installation carried out by Mr. C. E. L. Brown, electrical engineer to the Oerlikon Works was one of 50 horse-power, between Kriegstetten and Solothurn, a distance of 5 miles and gave a commercial efficiency of about 74 per cent.

A table giving the installations by the Oerlikon works of 50 horse-power or more contains a list of seventeen localities. The dynamos in each, with one exception, range from one to four, the capacity of only five of them exceeds 100 kilowatts, the largest being 310.

The maximum distance, found in two plants, is 8 kilometers or about 5 miles and in several the distance is only about a half mile. The exception above noted is Argentine Republic and Chile where there were 26 dynamos ranging from 24 to 54 kilowatts and there are two distances given, 3 and 7 kilometers respectively. The power was developed in many small motors principally or wholly for driving air compressors in the construction of tunnels on the trans-Andine Railway.

No reference is made in the text of this book by Gisbert Kapp to alternating current. All of the transmissions above described appear to have been direct current employing the constant current system in which in general a generator supplies current over its own circuit to its own motor.

It was natural that this development should have progressed rapidly in Switzerland where there were many sources of water-power and no coal. The mountainous country often prevented the location of the mill at the waterfall, consequently wire-rope transmission had been largely used between them and electric transmission from a waterfall to a mill found a promising opportunity.

The presentation of power transmission in Kapp's treatise appears to have no suggestion of a system for the general transmission and distribution of power.

The promoters of the Niagara project for 200,000 horse-power involving distances of 20 miles and more, could have found little satisfaction in this treatise on the electrical transmission of energy by a foremost electrical authority and writer in the record of things accomplished; they might, however, have been inspired with a hope for the future in the following sentences from the preface.

C. E. L. **Brown**
(Brown, Boveri & Company)
Baden, Switzerland

> Another subject which might have found a place in the present volume is that of power transmission by means of alternating currents. It is quite possible that for the transmission of *very large powers* over *very long distances*, the alternating current *may eventually* prove more convenient than the continuous current, but as up to the present no such transmission plant has yet been erected, the subject must still be regarded as in the *experimental stage*, and not ripe for discussion in a book which, being intended for practical men, should deal with accomplished facts rather than with possibilities.

"HIGH TENSION CURRENTS," BY CHARLES E. L. BROWN

On February 9, 1891, the week after the dissolution of the International Niagara Commission in London, C. E. L. Brown, the electrical director of the Oerlikon Engineering Works at Oerlikon, Switzerland, read a paper[1] in Frankfort before the German Electrical Society (Elektrotechnischer Verein) entitled, *High Tension Current, Its Generation, Distribution and Utilization*, having special reference to the use of high tension for the transmission of electric power over long distances.

He pointed out the difficulties and limitations in the use of direct-current machinery and explained the ideal simplicity of the alternating-current transformer and its practical adaptation for high voltages when oil was introduced as an insulating medium. For transmission, he proposed porcelain insulators provided with a groove on the inside of the lower edge to be filled with thin oil for insuring adequate surface insulation. He suggested high iron poles, separated as much as 200 meters. For driving large individual motors and for electric lighting, the ordinary alternating current was indicated as sufficient, but for the general operation of small motors and lighting "we will use the polyphase alternating currents which likewise include the possibility of most varied use in motor operation."

He then refers to his own experiments: "Naturally I would not like to have it said that all the questions coming into consideration here have been definitely solved. Only larger practical experience can bring about these solutions and at present we have only some preliminary experiments carried out on a small scale which naturally can in no way as yet give definite conclusions on all points."

He then described tests made at Oerlikon on a short transmission line at 30,000 volts in which the line losses over insulators, the matter of especial concern, were found to be negligible. These tests were preliminary to his project for the generation and transmission of about 100 horse-power from Lauffen on the Neckar River to the city of Frankfort, more than 100 miles, then in preparation for the exhibition to be held in that city in the following August.

He concludes his address with the following paragraphs:

> The transmission of electric energy by means of current tensions of, for example, 30,000 volts is possible, the distribution of energy to great distances by electrical methods is a fact and this will lead to the utilization of many sources of power now slumbering and make the blessings of the electric current serviceable to the greatest extent to all industry.
>
> The erection of such installations according to the criteria set up by myself and according to the preliminary experiments made, seems possible without qualifications; however, I do not conceal the fact that with their practical execution a great deal will be learned and will be improved which does not detract from our present opinions.
>
> Let us hope that the electro-chemical exposition to be held here in the coming months may encourage new advances in this field and secure the conversion of many doubters of the tremendous importance and ability of technical electricity.

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[1] See Appendix N, Volume II.

Upon receipt of notice in October, 1891, of the retirement of Mr. Brown from the Oerlikon works, the president of The Cataract Construction Company invited him to consider the establishment of new engineering works at Niagara Falls and offered to promote its formation and business. His reply showed that having already founded the firm of Brown, Boveri & Company at Baden (Switzerland), it was not practicable for him to become personally identified in the Niagara enterprise proposed.

Soon after this negotiation The Cataract Construction Company announced that it had

> decided to establish in connection with the hydraulic works of The Niagara Falls Power Company, at Niagara Falls, New York, a central station for generation and distribution of electrical energy for power and lighting purposes.

Proposals were invited from Swiss engineering works of designs for a central station and its machinery suitable for hydro-electric units of 2500 horse-power generation and local distribution. The Swiss designs submitted in this connection were so promising that negotiations were opened for terms and conditions of contract for manufacture in Switzerland or for construction in the United States under Swiss supervision.

To the inquiry as to the guarantee of operation and the protection of the designs against liability for infringement of patents in the use of such machines at Niagara Falls as they proposed, the Oerlikon Company stated positively that it would not guarantee the design against patent infringement. The negotiations ceased. There appeared to be disappointment on both sides, but the cataract company insisted it would not purchase otherwise, a position that was maintained in the entire installation of its Niagara plants.

Further study of this subject led to the decision for 5000 horse-power units and for an installation of alternating current for long distance as well as local transmission—one system with the feasibility of divers uses.

SUMMARY: THE NIAGARA PROBLEM

Briefly summarizing the state of the art of electrical transmission in 1890: there were various systems using currents of different character and at different voltages and requiring independent generators and independent circuits for different kinds of lighting service and for railway operation. There was but little power and it was generally incidental to lighting. Where there was comparatively long-distance transmission by direct current there was usually an individual generator supplying constant current to its own motor. Where longer distance and large power were involved it was proposed to operate several generators in series as a single unit and also to operate several motors but the several motors were usually used for driving a single load, usually dynamos in a sub-station. The commercial operation at Telluride in which 100 horse-power was transmitted 3 miles at 3000 volts in 1891, and the experimental transmission to the Frankfort Exposition of alternating current from a 300 horse-power hydro-electric station at Lauffen on the Neckar River, over a distance of 100 miles at 30,000 volts, in the fall of 1890, are the principal power transmissions of that period, both of them subsequent to the preliminary decisions as to Niagara power policies. The contemplation of the use of electricity from hydraulic units of 5000 horse-power in a plant which would ultimately aggregate 100,000 horse-power or more, which approximated the output of all the electric lighting stations in this country, required imagination, optimism and confidence that the plants then in operation were a promise and a prophecy of larger things which might be developed within a few years.

Electric power, with incidental lighting, instead of electric light with incidental power, was the new condition which Niagara presented. The ideal plant should supply all kinds of service from generators and circuits of a single type instead of the many types which were then necessary. It should be capable of supplying large amounts of power to Buffalo and beyond. It should be a universal electric power system. It should be different in kind and in size from anything then in existence.

The report of the International Niagara Commission containing proposals by many leading engineers and manufacturing organizations of methods for transmitting power is an authoritative presentation of the state of the art in 1890. It merits careful perusal by the student of electrical history. Only two of the many proposals advocate alternating current, and Professor Forbes alone, proposed polyphase currents. And his recommendations were based on theory and expectation rather than accomplishments.

ALTERNATING-CURRENT PLANTS IN OPERATION MAY 6, 1893

During the period from 1889 to 1893, in which the project of The Niagara Falls Power Company was being developed through the agency of the International Niagara Commission which secured projects from many of the leading engineers of the world and through continued investigations and studies by its technical staff and by manufacturing companies concerning themselves with the Niagara program, there was a continuing increase in the general use of electric power. Alternating-current plants for the lighting of cities and towns and for the transmission of current for this purpose from distant hydro-electric plants were increasing in extent and in importance. The great development during this period, however, was in the design and construction of electric machinery. New types of apparatus, such as the induction motor and the rotary converter, were being developed, and great improvements were being made in the design and construction of electric generators and transformers. All this made possible a continuous advance in the electrical service rendered, and it gave promise of larger and continuing development in the future.

The state of the art on May 6, 1893, when the directors of The Niagara Falls Power Company officially decided on the adoption of polyphase alternating current is of particular interest, as indicating to what extent their decision was based on actual practical accomplishment and to what extent upon faith and hope that electrical engineers could produce apparatus much larger in size than had ever been built and that new types which were then hardly beyond the stage of experiment would prove successful.

A review of plants in operation shows that the outstanding actual achievement in power transmission was at Telluride where a 100 horse-power synchronous motor had operated for two years under adverse physical conditions. The maximum size of single-phase alternating-current generators was about 1000 horse-power and there were no polyphase plants in commercial operation which were of sufficient size and importance or which had been operating long enough to be a factor in the Niagara determination. Several plants had been sold and were under construction indicating confidence in this type of electrical system, but so far it was promise rather than performance.

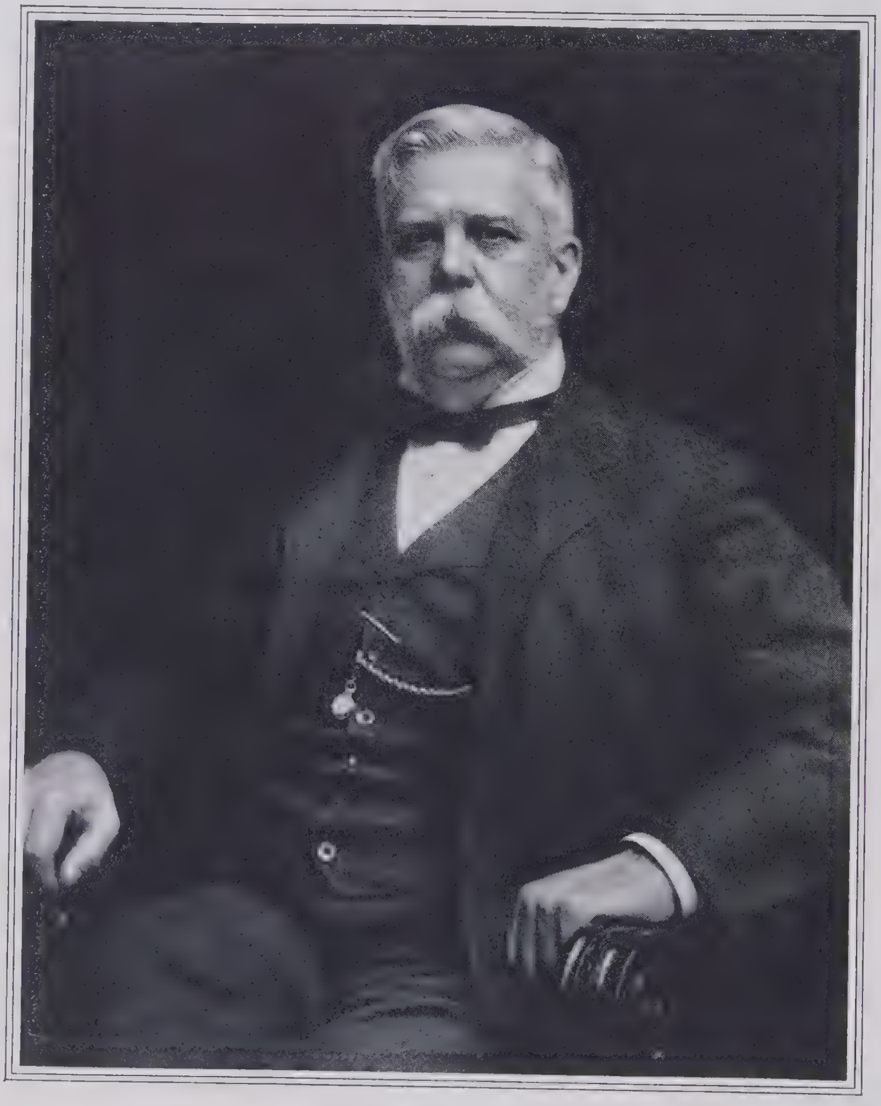
The tests for the Frankfort Exposition in 1891 demonstrated the feasibility of transmitting power 100 miles by polyphase alternating current and the apparatus at the Chicago Exposition in 1893 showed how polyphase power could be converted and transformed for supplying all kinds of electric service. These exhibits, described elsewhere, presented in miniature in units of a few hundred horse-power, what was proposed at Niagara on a scale of 100,000 horse-power.

The foregoing summarizes the practical basis on which the technical advisers of The Niagara Falls Power Company based their recommendation and upon which its directors took action. When one visualizes the far-reaching importance of that decision and the disaster which would have followed from failure, there comes an appreciation of the vision, the imagination, the judgment, the daring and the courage which were exercised in deciding upon the new solution for the new problems with which they were confronted. It was an adventure into the unknown. Now we measure the success by the results. But we can scarcely appreciate the meagerness of the experience upon which so important decisions were based and the seriousness of the problems which were yet unsolved.

AMERICAN ORGANIZATIONS FOR THE MANUFACTURE OF ALTERNATING-CURRENT APPARATUS

CHAPTER XXII

WESTINGHOUSE ELECTRIC
AND
MANUFACTURING COMPANY



George Westinghouse
1846–1914
Engineer, Inventor,
Captain of Industry

AMERICAN ORGANIZATIONS FOR THE MANUFACTURE OF ALTERNATING-CURRENT APPARATUS

CHAPTER XXII

WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY

1886

GEORGE WESTINGHOUSE ESPOUSES ALTERNATING CURRENT

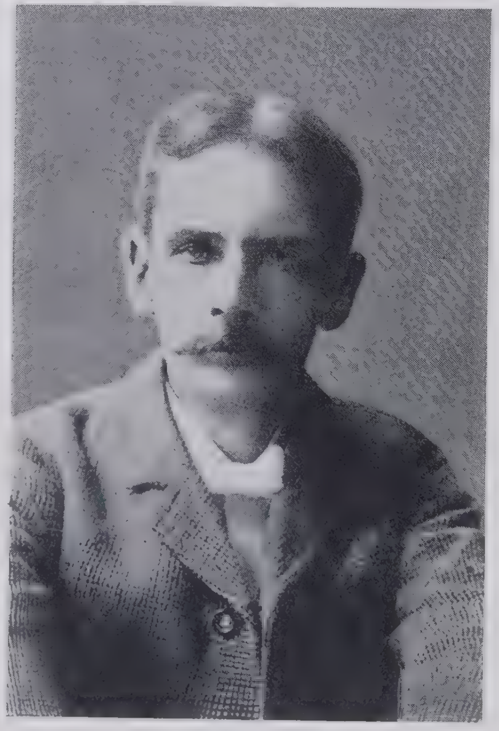
THE organization of the Westinghouse Electric Company in 1886 (succeeded by Westinghouse Electric and Manufacturing Company in 1890) marked the embarkation of George Westinghouse, inventor of the air brake, upon a new field of manufacturing for which his experience as mechanical engineer and inventor particularly qualified him.

His serious interest in electrical matters had been aroused by information regarding the Gaulard and Gibbs system of alternating-current transmission in which a small current at high voltage could be carried over small wires for a long distance and then transformed to a large current at low voltage suited for incandescent lamps and other uses.

He saw that by the new system the distribution of electricity might be extended far beyond the limits practicable by the methods then in use; he acquired the Gaulard and Gibbs patents; he imported apparatus from England and began testing and developing it in 1885. It was soon arranged that William Stanley, a member of his electrical staff in Pittsburgh, should devote his energies to the problem.

Stanley had been interested in alternating current phenomena and had experimented with the action of coils in previous years, and was in position to appreciate the new problems. He returned to his home in Great Barrington, Massachusetts, established a laboratory and shop in an old rubber mill, recognized the limitations of the constant current method employed in the imported apparatus in which the primary windings of the transformers were connected in series, adopted a constant potential system in which the primary windings are connected in multiple or parallel, designed and built a number of transformers (then termed secondary generators and later converters) and placed them at various houses and stores for supplying incandescent lamps. The current was transmitted at 500 volts from an imported Siemens' alternator. Operation began March 16, 1886, and soon afterwards Mr. Westinghouse and party inspected the plant. Their favorable impression led to the active development at Pittsburgh of alternators (following a new design of

Stanley's), transformers and other appliances. So rapidly was this work pushed forward that by the end of the year several equipments had been shipped to various localities for installation in commercial lighting plants.



William Stanley
Pioneer Electrical Inventor

In October, 1887, Mr. O. B. Shallenberger, electrical engineer of the Westinghouse Company, made the following statement:

> The first commercial plant was put in operation in Buffalo, New York, in November, 1886, and has been in successful operation since that time as a commercial plant. Since that time a number of commercial plants have been installed reaching between thirty and forty and varying from 650 to 10,000 lights of 16 candle-power capacity. More than thirty plants in addition have been sold but not yet installed.

The alternating current was single phase, 133 cycles and was transmitted at a little over 1000 volts to transformers placed at residences and stores which lowered the voltage to 100 volts or 50 volts for lighting. As a distance of several miles could be economically served by this system it was superior to ordinary direct current for incandescent lighting which found its limit well within a single mile. But the new system was handicapped by having no meter to measure the service to the consumer and it had no motor.

In 1888 two important advances were made: Shallenberger in the Westinghouse laboratory invented the induction meter and the Tesla patents for the polyphase induction motor were issued and acquired by Mr. Westinghouse. The new meter and the new motor were simpler in construction and operation than the corresponding direct-current apparatus and their advent gave a great impetus to the alternating system.

BEGINNINGS OF ALTERNATING CURRENT AND OF THE NIAGARA PROJECT

It is interesting to compare the dates of the beginnings of the alternating current and the starting of the project which eventuated in the electrical development at Niagara. The practical demonstration of alternating current for lighting at Great Barrington, beginning on March 16, 1886, preceded by just fifteen days the obtaining from the New York Legislature of a special charter which was the legal beginning of The Niagara Falls Power Company. The issuing of the Tesla polyphase patents in May, 1888, was followed a year later by the organization of The Cataract Construction Company which undertook the investigation of methods of developing Niagara power. Niagara plans and alternating-current machinery developed simultaneously and in less than a decade they mutually contributed to the inauguration of modern hydro-electric power service.

The first alternating current central station in America began operation in Buffalo on November 30, 1886, for supplying a few hundred incandescent lamps. On November 15, 1896, the Niagara-Buffalo transmission line brought Niagara power to Buffalo as polyphase alternating current, inaugurating universal electrical service.

THE POLYPHASE SYSTEM

The new motor, however, required for its operation a polyphase current, either two-phase or three-phase. This necessitated a generator which could supply two or three alternating currents whose impulses follow one another in much the same fashion as the reciprocating pistons of an engine with several cylinders so that in both cases the successive impulses give a resulting turning effort that is uniform. But the generators then in use were not of that type, and the standard frequency of 133 cycles was too high for satisfactory operation of induction motors.

Hence a new type of generator and of distribution circuit was necessary, so that the commercial introduction of the motor involved much more than its own design and development. The polyphase motor, therefore, did not meet the immediate call for motors to be operated from lighting circuits. Several installations of Telsa motors and two-phase generators for operating machines for mining coal were installed, but the polyphase system for general lighting and power service was not developed and introduced until several years later. In the meantime, there was continued extension of commercial lighting by alternating current and the experimental development of apparatus of large sizes and for higher voltages, all of which was paving the way for later and larger achievements. Several of the Westinghouse undertakings which were notable advances were the 12-mile transmission from Willamette Falls to Portland, Oregon, the synchronous motor at Telluride, Colorado, and the 10,000 volt, 30-mile transmission in Southern California, which used oil-insulated raising and lowering transformers. These were inaugurated respectively in 1890, 1891 and 1892. The largest machines in these installations

Lewis B. Stillwell
Chief Electrical Engineer
Westinghouse Electric and Manufacturing Company

did not exceed 150 horse-power and the largest transformers were less than 10 horse-power.

EUROPEAN INVESTIGATION AND THE NIAGARA PROJECT

In 1889–1890 Lewis B. Stillwell, then assistant electrician of the Westinghouse Company, made a tour of Europe to ascertain the state of electrical development in various countries, particularly in England, France, Italy, Austria-Hungary, Germany and Switzerland. He visited the chief centers of electrical activity and examined some of the more important hydraulic installations.

Mr. Stillwell's survey of the European electrical systems in use in the early part of 1890 showed direct-current apparatus for the three-wire system, at 200 volts, in units of 1000 horse-power, direct driven by steam engines in process of installation in Berlin for lighting purposes. An alternating-current single-phase generator of 1000 horse-power direct connected, producing current at 2000 volts was under construction in Hungary.

He was present in London during the organization and first meetings of the International Niagara Commission in June, 1890.

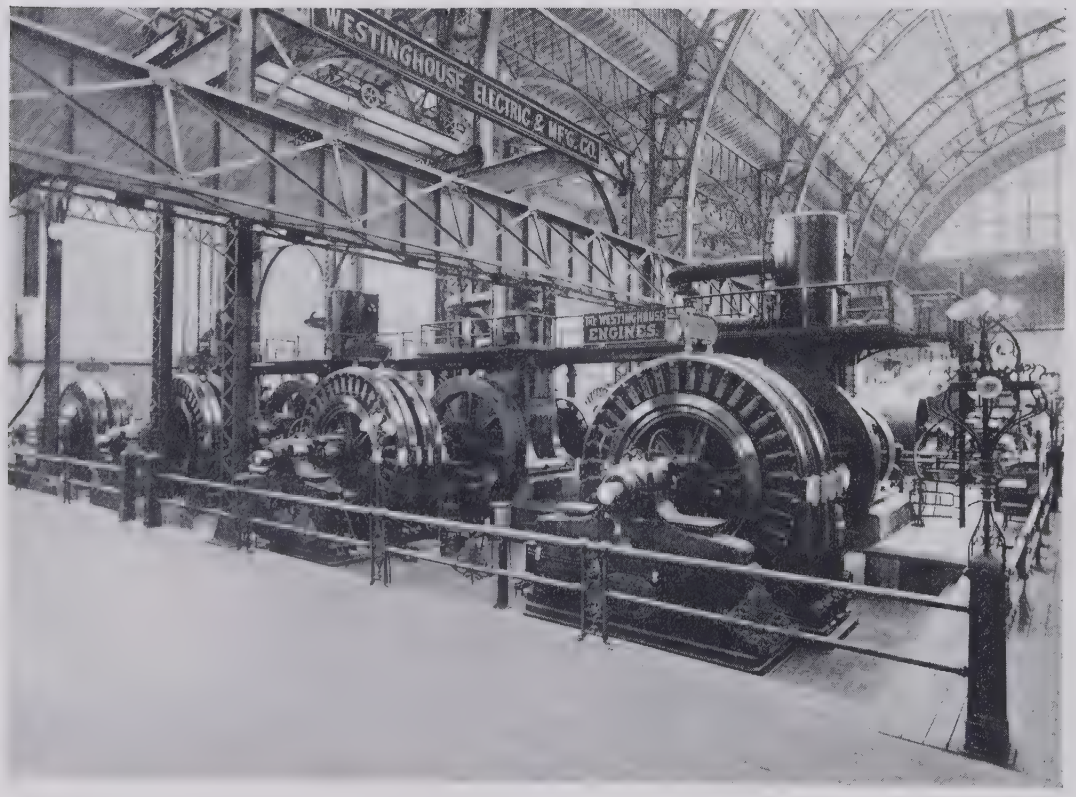
H. M. Byllesby, vice-president of the Westinghouse Company, was also in London at that time, having just completed the organization of the British Westinghouse Company, Ltd. Mr. Westinghouse was thereby enabled to have prompt information regarding the progress of electrical engineering abroad, by which he could be guided in the development of his manufacturing operations which soon became so extensive in the fields of electrical industry in the United States.

Mr. Westinghouse and his staff were not leaning heavily upon European developments. They were influenced, however, by examples of direct-connected engines and generators in Berlin and Budapest and by the successful use of low frequency (42 cycles) for arc lighting as well as incandescent lighting by the Ganz Company.

Mr. Stillwell, accompanied by Reginald Belfield, the electrician of the new British Westinghouse Company, conferred with President Adams and Chief Engineer Sellers of the Niagara company in London regarding their problem and their plans for the International Niagara Commission. Mr. Stillwell at the first interview advocated alternating current and stated that he was very eager to have his company enter the competition, but Mr. Westinghouse refused. Subsequently he informed Mr. Stillwell of his reason, to the effect, that "these people are trying to get $100,000 worth of information for a prize of $3000. When they are ready to do business, we will submit a plan and bid for the work."

The facts bearing upon these statements of Mr. Westinghouse are as follows:

Although no plan deemed worthy of the first prize was submitted to the commission some of the important results of the organization were (1) a demonstration that the written and published accounts of the state of the art of generation and transmission of power were several years behind its practise, while much remained to be done that had not yet been worked out, the situation being as expressed on the ex libris of the American Institute of Electrical Engineers, "Science precedes books and not books science"; and (2) it resulted in an expenditure by The Cataract Construction Company abroad of not less than $430,000 for services and materials utilized at Niagara in the harnessing of the falls.



ALTERNATING CURRENT POWER-PLANT AT WORLD'S FAIR, CHICAGO, 1893

Four of the twelve 1000 horse-power two-phase generators

POLYPHASE CURRENT OF THE CHICAGO WORLD'S FAIR

Development of alternating-current apparatus was rapid. Lighting plants for towns and cities were continually increasing in number and size. The outstanding event was the lighting of the World's Fair at Chicago in 1893. After a bitter commercial struggle and with financial, engineering, manufacturing and patent difficulties to overcome, Westinghouse and his alternating current won. The construction of twelve polyphase alternators of a thousand horsepower each and the electric illuminations of a great White City for the first time in history were great events but they were overshadowed in real significance by a more important though less spectacular exhibit.

Col. Henry G. Prout in his *A Life of George Westinghouse*[1] concludes the chapter on the Chicago World's Fair, 1893, with these significant paragraphs:

> Quite apart from the lighting plant, the Westinghouse Company showed at the World's Fair a complete polyphase system. A large two-phase induction motor, driven by current from the main generators, acted as the prime mover in driving the exhibit. The exhibit, then, contained a polyphase generator with transformers for raising the voltage for transmission; a short transmission line; transformers for lowering the voltage; the operation of induction motors; a synchronous motor; and a rotary converter which supplied direct current, which in turn operated a railway motor. In connection with the exhibit were meters and other auxiliary devices of various kinds. The apparatus was in units of fair commercial size and gave to the public a view of a universal power system in which, by polyphase current, power could be transmitted great distances, and then be utilized for various purposes, including the supply of direct current. It showed on a working scale a system upon which Westinghouse and his company had been concentrating their efforts; namely, the alternating-current and polyphase system.
>
> It has been maintained with some plausibility that the most important outcome[2] of the Centennial Exposition of 1876 was that the people of the United States there discovered bread. So it may be maintained with even more plausibility, that the best result of the Columbian Exposition of 1893 was that it removed the last serious doubt of the usefulness to mankind of the polyphase alternating current. The conclusive demonstration at Niagara was yet to be made, but the World's Fair clinched the fact that it would be made, and so it marked an epoch in industrial history. Very few of those who looked at this machinery, who gazed with admiration at the great switchboard, so ingenious and complete, and who saw the beautiful lighting effects could have realized that they were living in an historical moment, that they were looking at the beginning of a revolution.

POLYPHASE CURRENT FOR NIAGARA

In December, 1892, about eighteen months after the issue of the printed report of the International Niagara Commission and a year after the invitation for tenders, Mr. Westinghouse notified The Cataract Construction Company that his company was ready to present a plan illustrative of the electrical scheme it would propose for Niagara. It was the polyphase alternating current, 30-cycle system. Dr. Sellers and Professor Rowland, on behalf of The Cataract Construction Company, attended at that time various demonstrations at the Westinghouse factory including the operation of rotary converters and tests of incandescent lamps at various frequencies of alternating current. The officers of the cataract company made an inspection with their experts, after the latter had passed several days making the examinations.

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[1] Written for a committee of the American Society of Mechanical Engineers and published by that organization in 1921.

[2] The Vienna Bakery was the source of this "most important outcome."

Albert Schmid
Mechanical Engineer

The facilities of the Westinghouse Company were reported by the engineers of the cataract company as ample for such construction as was proposed, while the experience of such mechanical engineers as George Westinghouse and Albert Schmid constituted a guarantee of mechanical superiority, and the reputations of their electrical engineers, Lewis B. Stillwell, Oliver B. Shallenberger, Benjamin G. Lamme, Charles F. Scott, and others, combined to impress the Niagara management with the seriousness and the skill of the efforts that would be made to produce the electrical machines desired, although absolutely novel in design and unique in magnitude. Moreover, the fact that the Westinghouse enterprise was developed from a machine shop as a foundation into a great engineering structure, including important electrical works as its latest production, was a promise of favorable results, particularly in view of the declaration of Sir William Thomson (Lord Kelvin) that "an electrical engineer is nine-tenths mechanical."

ENGINEERING STAFF

When the Niagara enterprise began to take definite shape as an electrical project, with a board of engineers and technical experts retained to advise in the design and construction of a system of electrical generation, transmission and distribution, Mr. Stillwell was instructed to give his personal attention to Niagara affairs. While his official title was chief electrical engineer, he appears to have been in reality the general engineer on this Niagara work, both before and after the awarding of the contract. He was consulted by all co-workers, dealing directly with The Cataract Construction Company, and determining the general contract conditions.

Two of the Westinghouse staff of engineers, Albert Schmid, mechanical engineer, and Benjamin G. Lamme, electrical engineer, devoted themselves to the modification of the design submitted by The Cataract Construction Company[1] and its adaptation to the machine tools and mode of manufacture of the Westinghouse Company. The modifications proposed in the design and accepted by the cataract company were developed by these two engineers and constituted, with the fundamental umbrella design of Professor Forbes, the Niagara type of alternator that was installed to the extent of 50,000 horse-power in Power-house Number One at Niagara Falls under the primary contract of August 10, 1893.

The great importance of this contract and the wide influence of the successful machine it produced justifies a special reference to the two engineers who were mainly responsible for the electrical features of the design.

The signing of the contract for the generators was the great event in the history of The Niagara Falls Power Company. At that moment there was transition from the period of investigation of method to the stage of action.

For a century there had been attempts to use Niagara power, for seven years a franchise had awaited action, for four years there had been scientific investigation. The International Niagara Commission had asked for an engineering answer to this problem of Niagara power, and the company's experts had long weighed the relative merits of compressed air versus electricity; of direct current versus alternating current; of high frequency versus low frequency; of the designs of one manufacturer versus those of others. Now the discussions were at an end, the decisions were made and the verdict was sealed in a contract. Henceforth success depended upon the physical performance of the generators—upon the correctness of designs and the integrity of materials and the excellence of workmanship in the construction of machines which were without precedent.

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[1] See letter of invitation of August 10, 1893, Chapter XXIII, and Appendix M.

The contract placed upon the Westinghouse Company full responsibility for performance. The "preliminary design" of the generator presented by the cataract company proposed an external field ring and a special form of armature winding with an oil circulating system for insulating and cooling the armature coils. Specifications regarding the "umbrella type" of field were agreed upon, the Westinghouse Company, however, being invited to employ such modifications of design as it deemed necessary in order to guarantee the efficient working of the machine, adopted a different type of winding and method of insulation.

Many minds in America and abroad had contributed during several years to the decision as to what should be done; now the responsibility for bringing that decision to successful fruition rested upon two of the Westinghouse staff of engineers, Albert Schmid, mechanical engineer, and Benjamin G. Lamme, electrical engineer.

Albert Schmid, a Swiss mechanical engineer, in the employ of the French Westinghouse Air Brake Company, was personally selected by Mr. Westinghouse to come to the United States to work with the American brake company in 1885. His keen mechanical perception and aptitude in developing ideas on the drafting board soon led to his becoming chief designer and engineer when the Union Switch and Signal Company began its electrical development.

Upon the formation of the Westinghouse Electric Company in 1886, Albert Schmid was chosen to co-operate with electrical engineers in working out the mechanical designs of the new apparatus. His artistic taste and mechanical ability combined to produce forms which were simple, robust and graceful. In the period of early electrical development he placed his characteristic stamp on the apparatus manufactured by his company.

In the Niagara contract he recognized opportunity for great achievement and he did his best. He was not only chief designer but was maker as well, as he was superintendent of the company in charge of both its manufacturing and drafting departments.

B. G. Lamme, recently graduated from college, began working for the Westinghouse Company in 1889, just at the time that the cataract company began its scientific investigations as to means of developing Niagara power. His first duties were routine, but some of his characteristics soon came to the attention of Mr. Schmid and he was given tasks of increasing importance in the testing room. He was a close observer and a clear reasoner; he showed remarkable aptitude in analytical reasoning; he understood the fundamental principles underlying electromagnetic apparatus; he applied these principles in design and produced new and rational types. The development of electrical apparatus during the '80's had been largely by cut-and-try methods. The result was a score of forms of field magnets which gave endless variety to the types

BENJAMIN G. LAMME
ELECTRICAL ENGINEER

and appearance of dynamos and motors. Lamme was leader in adopting a rational form of magnetic field circuit and in devising simple and ingenious forms of winding. These were the result of careful analytical study and painstaking calculations. He did not imitate, he originated.

Within a few years he had produced a new type of direct-current generator and a new type of street railway motor, several of the outstanding features of which have become the universal standard. Then the apparatus for the Chicago World's Fair gave proof of his versatility and ability as he designed successful generators for the power plant which exceeded all predecessors in aggregate capacity, and machines of various sizes and types for a special exhibit. The latter included generators, synchronous motors, induction motors and rotary converters and constituted the first large scale exhibition of a complete polyphase system including large rotary converters for producing direct current. It was a notable event in electric history.

The design of the Niagara generator came to Lamme as an opportunity and also as a challenge of his ability as a designer. A statement regarding the Niagara generators, prepared by Mr. Lamme for this history, after they had been in service for twenty-five years, appears as Appendix M to this volume.

It was fortunate for both the Westinghouse and the Niagara companies that the making of the generators fell to the lot of two such capable young engineers, Schmid, who was then 36 years of age and Lamme, who was only 29.

Among other engineers whose activities and skill were devoted in allied departments to the development of design and construction of the Niagara plant, were the following:

Oliver B. Shallenberger, consulting electrical engineer, who developed a new type of induction measuring instrument which was designated "Niagara Type."

Charles F. Scott, consulting electrical engineer, who acted in an advisory capacity in many important ways. Shortly after the alternator contract was awarded to the Westinghouse Company, Mr. Scott proposed the method of transformer connection by which the two-phase current from the generators was transformed to three-phase current for transmission to Buffalo.

C. E. Skinner had much to do with the development of the mica insulation on both the armature and the field of generator.

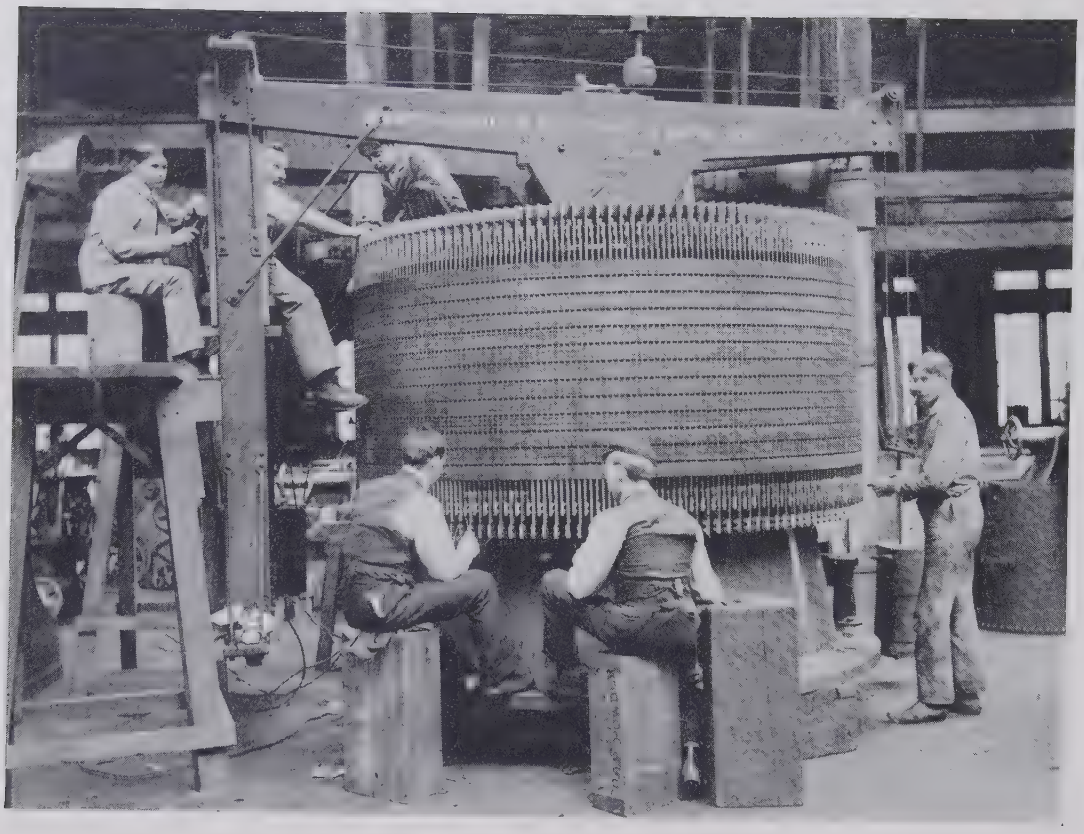
H. P. Davis, Alexander Wurts and Henry Noel Potter were also actively associated with the work, particularly in connection with control switches, lightning arresters and other auxiliary apparatus.

Among others who were prominent in the work were Paul M. Lincoln, Phillip Lange, E. C. Means, W. K. Dunlap and Messrs. Sigfried, Boegel, W. F. Lamme, Beinitz, Wright, Friedlander, Strauss, Mould and Parks.

The Westinghouse Company made due acknowledgment of the assistance of Dr. Coleman Sellers, president and chief engineer of The Niagara Falls Power Company, and of De Courcy May, later superintendent and engineer of The Cataract Construction Company, who were in repeated consultation with Mr. Schmid and his assistants and made many valuable suggestions.

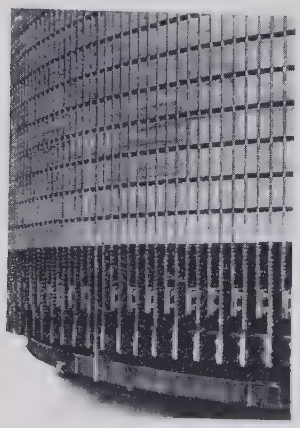
Charles F. Scott
Consulting Electrical Engineer

Mr. Stillwell said in referring to his associates in developing and constructing the Niagara alternators: "We all worked together with enthusiasm and harmony, directed and inspired by Mr. Westinghouse, who kept very closely in touch with every important development."



Armature of 5000 Horse-power Generator

Ends of vertical conductors are being insulated. Cylindrical iron core is composed of horizontal thin iron plates, with horizontal ventilating ducts



Armature of Early 5000 Horse-power Generators

View of small area of surface. Vertical conductors, mica insulated, extend down from slots in iron ore to connectors, edges of horizontal thin iron plates form armature surface; ventilating spaces three inches apart

Although the electrical design was turned over to Mr. Lamme, and the mechanical design to Mr. Schmid, Mr. Lamme pointed out that he had daily consultations with Mr. Stillwell, general engineer on the work, and with the other engineer on all important features, and that his great undertaking, like most large engineering feats, was the result of co-operation of many able and constructive minds.

PIONEER FEATURES OF NIAGARA EQUIPMENT

These early Niagara machines, described in another chapter, were pacemakers. They were still apparently as good as new after having served most efficiently for more than twenty-five years, which makes them patriarchs in the electrical field. They possessed novel and important features of construction, and are entitled to full credit for initiating the large-scale use of the polyphase system into the electrical world.

The auxiliary electrical apparatus including exciters, measuring instruments and switching devices were designed and constructed by the Westinghouse Company. A new type of switchboard indicating and integrating meters involving the induction principle were designed by Shallenberger and christened the "Niagara Type." Another innovation was the electro-pneumatic operation of switches in which an auxiliary circuit operated electromagnets which controlled the air valves of cylinders, in which were pistons which could exert large and sudden forces to open or close the switches. A switch for normally handling a thousand amperes in each of four conductors from a 2000-volt, 5000 horse-power generator was a step in this field comparable with that taken in generator construction. A new type of open-air switch with a non-arcing-metal shunt was provided and did duty for many years. Water-cooled, oil-insulated transformers which were here introduced are now used for the highest voltages. The bus-bars were of a new type and in their construction the Westinghouse Company was assisted by the Brown and Sharp Manufacturing Company of Providence, Rhode Island, and Dr. Habershaw, president of the India Rubber and Gutta Percha Company of New York.

PAUL M. LINCOLN[1]

One of the electrical engineers in the Westinghouse group that produced the first three Niagara alternators under the original Westinghouse contract was Paul M. Lincoln, who joined the forces of the Niagara company in the summer of 1896, as operating superintendent at first and later as resident electrician. His activities pertained particularly to the Westinghouse machines of Power-house Number One and the transmission to Buffalo that was first operated commercially November 15, 1896. He remained at Niagara until 1902, when he rejoined the Westinghouse engineering staff. He is now the head of the electrical engineering department of Cornell University.

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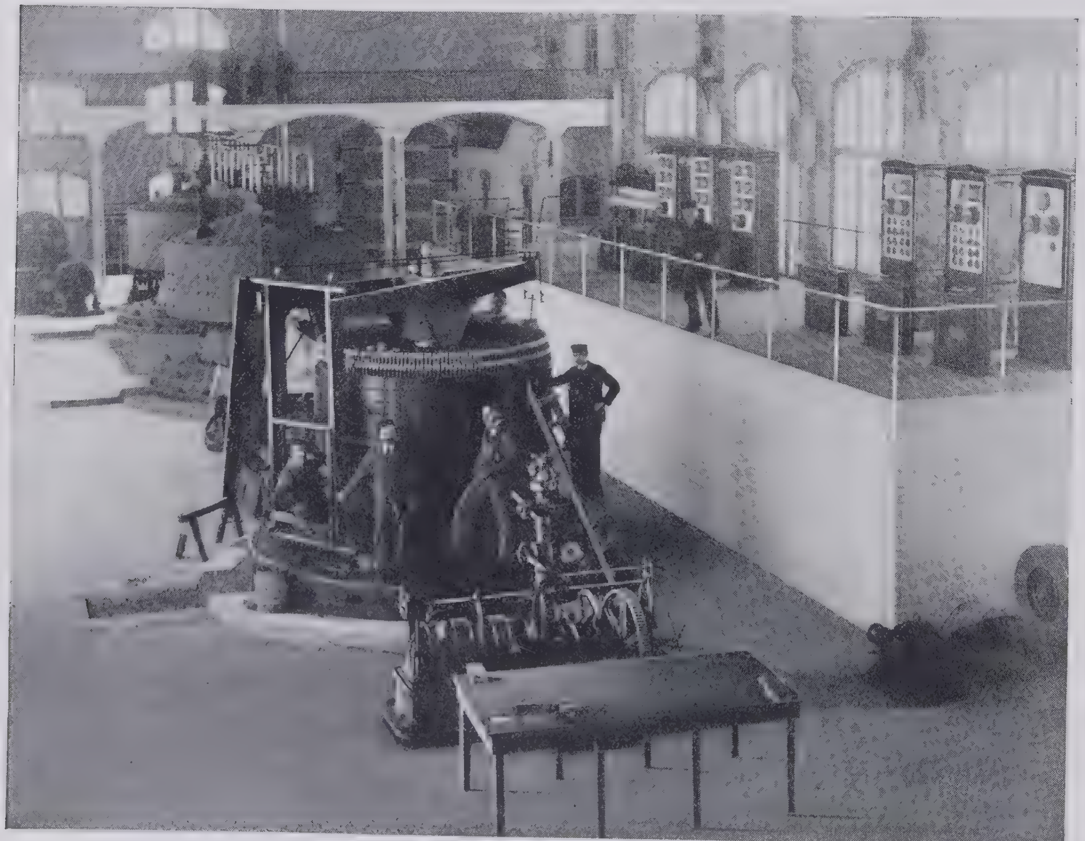
[1] For portrait, see Chapter XXVIII, Volume II.

LEWIS B. STILLWELL

After the construction, test and installation of the first three alternators,[1] by the Westinghouse Company, and after further contracts had been made with that company for additional units, Mr. Stillwell resigned his position as chief electrical engineer and assistant manager of the Westinghouse Company and accepted in March, 1897, appointment as electrical director of The Cataract Construction Company and The Niagara Falls Power Company, in charge of the electrical construction and operation of those companies.



Installation of Alternator Number Three in Power-house Number One

He resigned his position with the Niagara company in September, 1900, after the 50,000 horse-power installation in Power-house Number One had been completed, all the ten alternators and their auxiliary machinery having been constructed by the Westinghouse Company.

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[1] Alternator Number One was successfully installed in readiness for operation in April, 1895.

Upon retirement from the Niagara company in 1900, Mr. Stillwell entered the career of consulting electrical engineering, and became associated with numerous important transportation and other companies that, under his direction, adopted alternating-current systems as their sources of power. His personal familiarity with the state of the electrical art in Europe in 1889, pursuant to his special mission from Mr. Westinghouse to that end; his leadership in this country in overcoming, at the Westinghouse works, the novel conditions encountered in the construction of Niagara dynamos; and his contribution of inventions to solve some of the problems involved in the design, construction and operation of the first hydro-electric machines; all contribute to the weight of his statement in 1920 regarding the transformation of water-power at Niagara into electric power as wanted, that "the effects, direct and indirect, were of vast importance—comparable, in my judgment, to the successful operation of the first steam locomotive."

GEORGE WESTINGHOUSE

The attitude of George Westinghouse to the Niagara enterprise is of interest. In conversation with President Adams of The Cataract Construction Company in 1890 he stated that he was inclined to believe that a central station in Buffalo could produce electric power from coal and steam more cheaply than it could be transmitted to Buffalo from Niagara.[1] He said further that the alternating-current system would be found to be the only economical and practical system for the project. He further expressed the belief that pneumatic transmission to Buffalo would probably be adopted thinking it might be found cheaper than electrical transmission and having the advantage that it could be introduced in existing manufactories for use in their steam engines without the abandonment of anything more than the boilers. This view was doubtless in large measure due to the fact that a great deal of attention was being given in Europe to the pneumatic transmission of power.

Such views expressed by such a man prove unmistakably the inadequacy of existing electric systems for the Niagara task and they forecast the development of alternating current. He regarded the pneumatic method as more promising if immediate decision was to be made. The characteristics of Mr. Westinghouse are brought out in what followed. It has been stated that he declined to participate in the program of the International Niagara Commission. But continuously and comprehensively he and his staff worked upon the large problem of power transmission which Niagara presented. None of the projects presented to the commission in 1890 merited the award of the first prize. Westinghouse did not compete, but a few years later, in December, 1892, he stated that he was ready to present plans and to exhibit and demonstrate new types of apparatus which his company was prepared to furnish. The system which he presented was examined, approved and adopted and a little later, October, 1893, the Westinghouse Company was awarded a contract for the manufacture of three alternating-current, two-phase generators of 5000 horse-power each, for Power-house Number One. Subsequently the company furnished the remainder of the 50,000 horse-power installation for that station as well as the larger units for the Canadian plant, being in all about one-half of the entire electrical generating system of the Niagara company.

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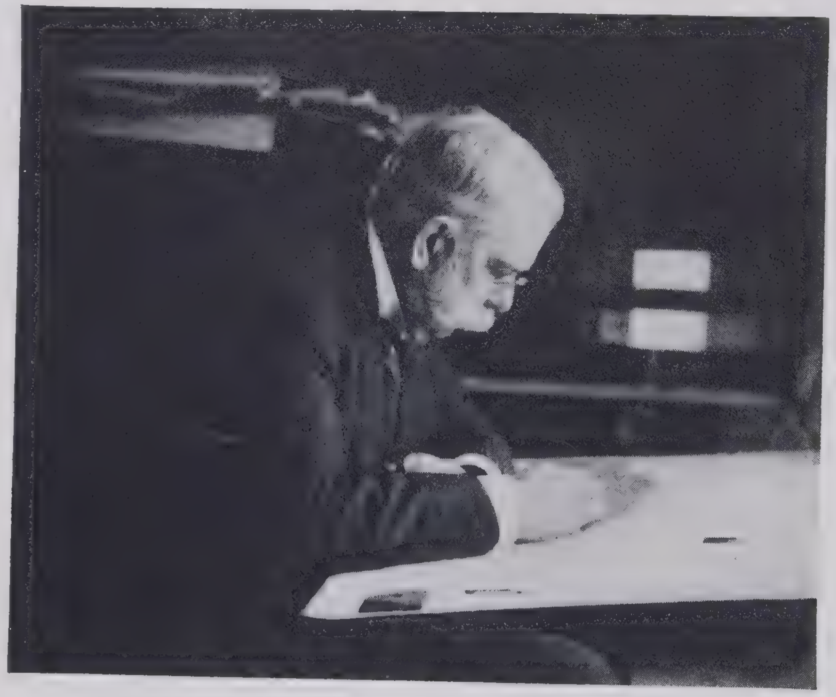
[1] The price of coal in Buffalo was then about $2.00 per ton.



George Westinghouse at Work

This award was appreciated by Mr. Westinghouse not only on account of its commercial significance, but because the selection of the polyphase alternating current in the greatest electric power project that had ever been undertaken justified the long effort he had made to secure the development and adoption of this system.

Colonel Prout states:

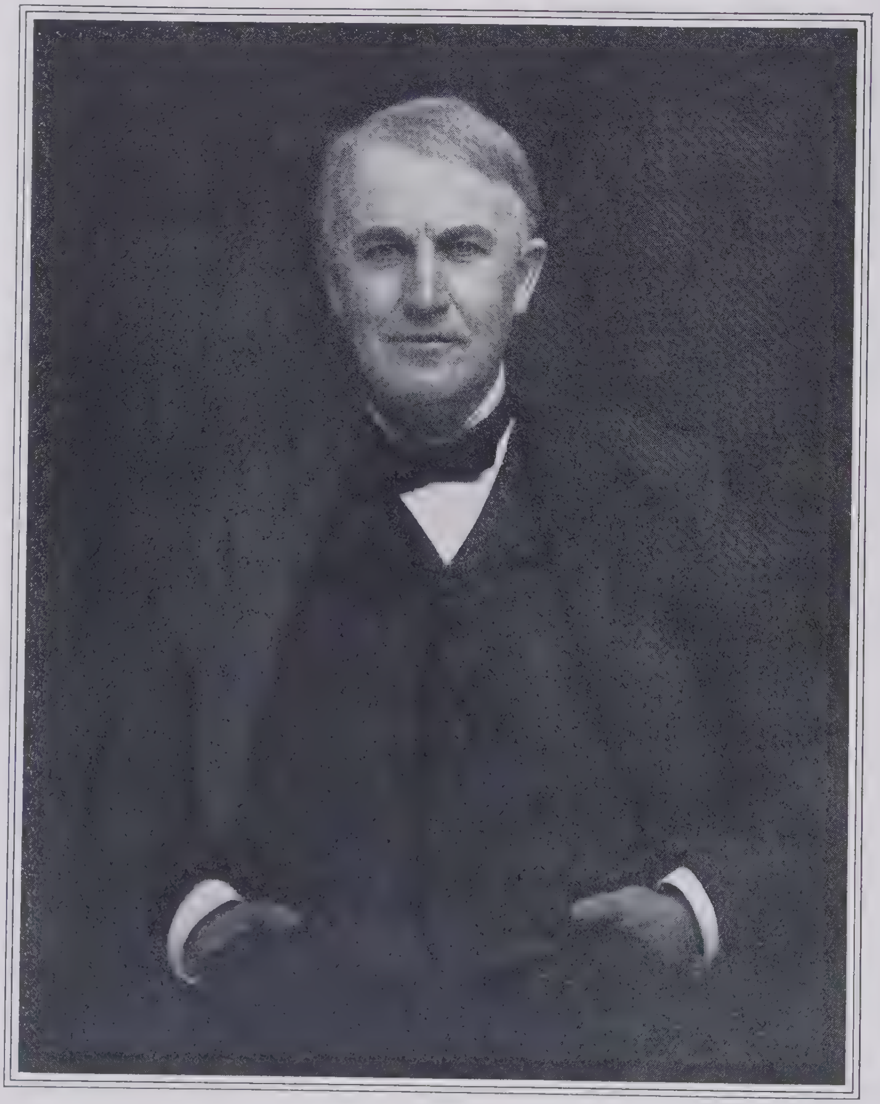
> Having seen his vision (alternating-current power system) Westinghouse proceeded, with his own unsurpassed fervor, courage and determination, and with his great intellectual power to develop it into physical being. He bought patents, he gathered about him a group of brilliant young engineers, and stimulated and guided them in design, invention and experiment, and through many and varied tribulations he moved steadily on to triumph. Considering the magnitude of his task, his progress was surprisingly rapid.
>
> His great service to mankind in this field of manufacture of power was in developing the use of the alternating current for the transmission and employment of electrical energy.
>
> The state of the electric art when Westinghouse first became seriously interested in the possibilities of the alternating current was like that of the railroad art when Sir Henry Bessemer brought forth his revolutionary invention for making steel . . . . . With characteristic modesty in one of his rare, lucid addresses, Mr. Westinghouse said: "To the part I took in bringing forward, in the eighties of the last century, the alternating-current system of electric generation and distribution, I owe much, if not all, of the reputation accorded me as one of the pioneers in what is now a great and important industry."

Colonel Prout concludes the life of his friend as follows:

> The consequent increase in the wealth, the well-being and the happiness of the people will be a fascinating subject for speculation for centuries to come. We venture to say, with due regard to the meaning of every word, that a thousand years from now, when scholars and philosophers try to measure the influence in the history of the human race of the era of manufactured power, and when they try to name the illustrious men of that era, they will write high in the shining list the name of George Westinghouse.

And the historian of the future in telling the story of electrical power will link Niagara with Westinghouse, and will record his participation in the harnessing of the great cataract as the opportunity which gave commercial realization to his great vision.

GENERAL ELECTRIC COMPANY



THOMAS ALVA EDISON
PRE-EMINENT INVENTOR
FOUNDER OF THE
ELECTRICAL CENTRAL STATION INDUSTRY

GENERAL ELECTRIC COMPANY

1891

ELIHU THOMSON, ELECTRICAL ENGINEER

The earliest worker in the alternating current field in the United States was Dr. Elihu Thomson, who built his first alternator in Philadelphia in 1878. It was a self-exciting dynamo electric machine, involving the principle of induction, and had collecting rings for two-phase current generated in its armature coils. This machine was used for demonstrations at the Franklin Institute of Philadelphia in 1879, for which Dr. Thomson constructed four transformers early in that year.

Thomas A. Edison had proposed in 1880 the placing of several direct-current generators in series for the generator and the motor stations, as a means of obtaining higher voltages for power transmission. This same method, and for similar purposes, was advanced by Dr. Elihu Thomson in 1883, and by Lord Kelvin in 1893.

An alternating-current dynamo connected to two transformers was produced by Dr. Thomson and used a few years later, but owing to the active development of what became the business of the Thomson-Houston Arc Lighting Company, not much attention was given to alternating-current machines until 1884, when the company, then known as the Thomson-Houston Electric Company, of Lynn, Massachusetts, resumed attention to alternating-current distribution. The work of the first year in this field was mainly directed to devising safeguards against the dangers then thought to accompany the use of high voltage alternating currents.

This preparatory experimental work was resumed in the fall of 1885, when Dr. Thomson took up actively the development of alternators and transformers, introducing many practical improvements in the design of such machinery meters, and various supplemental instruments.

His system of electric welding was developed from these alternating current experiments during this period. In 1888, he was engaged in experimental work upon single-phase alternating motors and in 1889 he exhibited a small motor of this type at the Paris Exhibition.

THOMSON-HOUSTON—GENERAL ELECTRIC COMPANY CONSOLIDATION, 1891

It was not, however, until 1891 when the Thomson-Houston Electric Company was consolidated with the Edison General Electric Company, of Schenectady, under the name General Electric Company, that preparations on a large scale were made for the commercial introduction of alternating-current machines upon a market already inquiring for that type of electric appliance.

CHARLES A. COFFIN, MASTER OF INDUSTRIES

Some of the principal men of this company moved from Lynn to Schenectady and organized the General Electric Company under the scientific guidance of Dr. Elihu Thomson and the leadership of that master of industries—always conservative but never retarding the sure advance of his organization in the electrical arts—Charles A. Coffin. Mr. Coffin became president of the company and in addition to Dr. Thomson gathered about him such men as Edwin W. Rice, Jr., C. P. Steinmetz, W. B. Potter, J. R. Lovejoy, A. L. Rohrer, George E. Emmons and others. Such an organization, representing the alternating as well as the direct-current systems, commanded the confidence of

DR. ELIHU THOMSON
PHYSICIST AND INVENTOR

The Cataract Construction Company in any design and proposal for construction the General Electric Company might recommend.

Neither the Edison General Electric Company nor the Thomson-Houston Electric Company submitted any project to the International Niagara Commission at its conferences in London in February, 1891. The interest in the alternating current on the part of the Edison General Electric Company was greatly increased by the reports from its representatives abroad respecting the claims made for this current by the electrical engineers who appeared before the International Niagara Commission to advocate their projects for Niagara, in which this current constituted a most interesting feature.

Charles A. Coffin
1845–1926
Founder and President of the
General Electric Company

The subsequent consolidation of the two companies was interpreted as resulting, in part, from the influence of the International Niagara Commission[1] and indicated preparations to enter the field of alternating-current development, with its high voltages associated with polyphase current systems, induction motors and rotary converters.

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[1] Organized and in conferences, June 21, 1890–February 4, 1891.

The organization of the General Electric Company just outlined was welcomed by The Cataract Construction Company as promising another large electrical organization, prepared, by its engineering staff and manufacturing facilities, to design and construct alternating-current machines and their supplemental apparatus.

Prior to the consolidation, the Edison General Electric Company had been the chief advocate of direct or continuous current in this country, while the Thomson-Houston Company, although identified scientifically with the alternating current, particularly through the inventions of Dr. Thomson, had not then become established as a manufacturer of polyphase current machines.

In the early autumn of 1891 the experimental demonstration was made of the high-voltage transmission between Frankfort and Lauffen, about 100 miles, to the electrical exhibition in Frankfort. This proved that the alternating current at high tension could be insulated and controlled and economically transmitted over considerable distance.

The staff of the new General Electric Company undertook the study of this alternating-current problem, and the preparation of a proposal for the generators on which it was anticipated they would be asked ere long to submit proposals for construction.

ALTERNATING-CURRENT MACHINES

After these events, development of this particular branch of electrical engineering proceeded with great rapidity, and, in 1892, The Cataract Construction Company invited American and European electrical manufacturers to submit proposals for alternating-current generators of 5000 horse-power each.

When considering, in the spring of 1892, electrical transmission as the only form of power distribution at Niagara, concentrated study was given to this subject by the officers of The Cataract Construction Company, with the highest authorities, particularly those not identified with the manufacture of electrical machinery.

Inquiries were made in March, 1892, respecting the facilities and disposition of the newly formed General Electric Company to enter competitive negotiations for contracts for power equipment at Niagara. Pres. Charles A. Coffin wrote that he had asked one of the best men from each of the companies (Edison and Thomson-Houston) to give the matter special and careful attention, and that Lieut. O. T. Crosby, of the Thomson-Houston Company, and Lieut. S. Dana Green, of the Edison Company, would look diligently after the matter.

In anticipation of the construction of the Niagara alternators, after deciding to adopt the alternating current, inquiries were addressed by the cataract company to the General Electric Company as to the construction of larger units than 2500 horse-power, such as 5000 horse-power dynamos, and the answer was promptly made September 14, 1892, "we are ready to undertake the construction of any size dynamos and motors."

William Le Roy Emmet
Inventor and Developer of
Electric Apparatus and
Power Mechanism

William Le Roy Emmet, a consulting engineer of the Edison and of the succeeding General Electric Company, was then placed in charge of all the engineering connected with the work of that company at and in the vicinity of Niagara Falls. This responsibility comprised all designing in Schenectady as well as the installation of the machinery ordered for the Niagara district, including the original installations of the Pittsburgh Reduction Company, the Carborundum Company, the Union Carbide Company, and other customers of The Niagara Falls Power Company.

The success credited to Mr. Emmet as designer and supervising engineer in the installation of his company's alternators, prompted The Cataract Construction Company to offer him the position of electrical engineer of The Niagara Falls Power Company in 1901, soon after the completion of the 50,000 horse-power installation in Power-house Number One, and the retirement of Lewis B. Stillwell, who had served the Niagara companies as electrical director from 1897 to 1900.

Mr. Emmet declined the appointment because, as he stated, he thought he "could do his best work in manufacturing." His recommendation of his assistant, Harold Winthrop Buck, was adopted, and Mr. Buck became electrical engineer, September 1, 1900, and continued until December 31, 1907, in responsible charge of the electrical engineering work of the allied companies—The Niagara Falls Power Company, Canadian Niagara Power Company, Tonawanda Power Company and the Cataract Power and Conduit Company.

GENERAL ELECTRIC PROPOSALS FOR ELECTRIC PLANT IN POWER-HOUSES NUMBERS TWO AND THREE

The General Electric Company's first offers were not successful, but its designs for the equipment of Power-house Number Two resulted in the company's receiving a contract to furnish the complete equipment of eleven generators of 5000 horse-power each. The General Electric Company also designed and constructed five alternators of 10,000 horse-power each for the Canadian plant of The Niagara Falls Power Company, with the result that what had been known as the Edison or General Electric Company provided about one-half of the entire alternating-current installations made in the three power-houses of The Niagara Falls Power Company.

These innovations in power-house generation and long-distance transmission and distribution, as well as somewhat similar experiences abroad among electrical manufacturers of transformers and motors, resulted in a change of public sentiment regarding the alternating current, and in convincing electrical engineers of the practicability of its control and use without the peril that was anticipated when the alternating current was first proposed for practical use.

Mr. Edison naturally was cognizant of these developments and gave much attention to this branch of the electrical art. He became familiar with the laboratory studies of the new company's scientists and profited by their successful response to the hydro-electric demands upon the manufacturers of electrical machinery in this country.

In the same broad-minded spirit that Lord Kelvin had shown when he promptly applauded the success of the Niagara enterprise with the alternating current, and that George Westinghouse early manifested in his frank admission in his competition with his system of alternating current as later developed for power transmission, Thomas A. Edison, the survivor of the three great leaders, long since recognized that the development of the alternating current for conveying power to central stations for distribution, has been a major influence during the past thirty years in the astonishing growth of the art of transmitting and using electric currents for light and power.

Positive Discharge from Induction Coil

Edison has the penetration to seize the relationship of facts and principles, and the art to reduce them to novel and concrete combinations.

PROF. JOHN TYNDALL

There is big money in it for those people, and I would like the glory of doing it, even if I didn't make much money. I can do it and have the facilities and nerve, as you know.

T. A. EDISON, ORANGE, NEW JERSEY,
NOVEMBER 23, 1886

EVOLUTION OF THE ELECTRIC SYSTEM AT NIAGARA

Chapter XXIII

EVOLUTION OF THE ELECTRIC SYSTEM AT NIAGARA

CHAPTER XXIII

ELECTRICAL VS. OTHER METHODS OF POWER DISTRIBUTION

THE choice of the system to be adopted for the distribution of power developed by the hydraulic turbines was the principal question before the directors of The Cataract Construction Company in 1890.

Mechanical drives by shaft, belt and cable were dismissed, after careful investigations, as inadequate for the quantity of power and the distance of transmission in contemplation.

Examinations of compressed air systems in use in England, France and America were critically studied by the company's officials, while the projects were in preparation for the International Niagara Commission. These examinations and conferences with the engineering advocates of the systems modified the favorable impressions first made.

Water under pressure was used in Europe to a limited degree and hardly at all in the United States. It was thought by some to be promising, mainly because this system, like compressed air, was simpler and better understood than electricity as a means for the transmission of power. Such installations also were examined. Both air and water projects were submitted to the International Niagara Commission in February, 1891, but neither received much favor.

THE ELECTRICAL SITUATION

The status of electric lighting and power in the early nineties, which has been presented in the preceding pages gives the background for appreciation of the problems which confronted those who were then dealing with the Niagara power development.

The situation regarding electrical transmission early in 1891 was presented in the final paragraphs of the report of the International Niagara Commission in these conclusions:

> The general opinion of the commission was in favor of the adoption of electrical methods as the chief means of distributing the power, though perhaps not as the only means. In the selection of electrical methods they were not convinced of the advisability of departing from the older and better understood methods of continuous currents in favor of adoption of methods of alternating currents.

It will be recalled that of the eight projects presented to the commission for power transmission, only four proposed electrical methods. Two of them advocated direct current and two alternating current, and of the latter, one recommended single-phase and one polyphase. Hence the question regarding which electrical system to adopt was vitally involved in the decision as to whether electrical or other methods should be adopted.

A careful consideration of the views, expressed in February, 1891, at the conferences in London of the International Niagara Commission with engineers presenting their electrical projects in competition for Niagara prizes and premiums, created the impression that representatives of the younger generation of engineers advocated the use of alternating current for long-distance power transmission. On the other hand the physicists and older scientists declined to recognize the polyphase alternating current, as available for use in the proposed plant at Niagara Falls for the distribution of its power.

Opposition to the use of alternating current was led in England by Lord Kelvin, and in the United States by Thomas A. Edison. The latter was then the leading advocate of direct current, the designer and manufacturer of incandescent lamps and of a system of distribution of direct current mainly for incandescent lighting. Lord Kelvin and Mr. Edison were supported generally by the constructing engineers of their respective countries, who were more familiar with the direct current, then extensively employed by them in electrical installations, chiefly for lighting purposes.

George Westinghouse then advised that the alternating system was the only economical and practical system for the Niagara project.

S. Z. de Ferranti, an English electrical engineer of London, was an ardent advocate of the alternating-current system, which he was actively engaged in establishing for the London Electric Supply Company, Limited. A generating station at Deptford, located on the bank of the Thames River, supplied current for transmission by cables about seven miles to a sub-station in the heart of that city for incandescent lighting. Mr. Ferranti and several other English electrical engineers were invited to submit plans to the International Niagara Commission, but did not avail themselves of the opportunity.

Prof. George Forbes, of London, well known as a consulting electrical engineer, who was frequently called upon to give expert evidence in electrical litigation and other such affairs, was one of the few persistent promoters of the alternating current for electric lighting and power.

There were two notable exceptions to the views of Lord Kelvin and Mr. Edison among foreign constructing engineers, Dolivo Dobrowolski, of Berlin, and C. E. L. Brown of Zurich, Switzerland, both of whom had designed and manufactured alternating apparatus including the equipment for the experiment of power transmission by the alternating current from the generating station at Lauffen-on-Neckar, to the exposition at Frankfort more than 100 miles away.

John W. Lieb, technical director of the Italian Edison Company, then resident in Milan since 1882, was one of the best informed American engineers respecting the development of the alternating current in Europe, having taken an active part in its introduction since 1886.

He participated in the tests of the Gaulard and Gibbs transformer at the Turin Exposition in 1884. He was acquainted with Professor Mengarini and his single-phase alternating-current transmission from Tivoli to Rome, installed about 1890, and was familiar with the alternating-current work of Ganz & Company, of Budapest, Hungary, who built the plant. As the Italian Edison Company represented Ganz & Company in Italy, many alternating-current plants throughout Italy were eventually installed under his direction.

PROVISION FOR ELECTRICAL AND COMPRESSED AIR SYSTEMS

How the investigation of the Evershed tunnel project, which initially contemplated many mills driven by individual wheels discharging through a common tunnel, led to the conclusion that there should be a central power station from which power should be transmitted for use both locally and at Buffalo and elsewhere has been related in earlier chapters. The desirability of such a plan was first indicated in the invitations issued in June, 1890, for projects to be considered by the International Niagara Commission but no formal decision had been reached.

The promising aspect of electrical methods of transmission and the consideration given by the commission to the use of compressed air for power transmission, largely owing to the character of the hydro-pneumatic projects submitted by prominent engineers of America, England, France and Germany, prompted The Cataract Construction Company to instruct its board of engineers to provide in its plan[1] of the inlet-canal, for two power-houses, one on each side of the canal, each for 50,000 horse-power to be developed by turbines in each case, but to be distributed in one case by electricity and in the other possibly by compressed air. The original and successful work by George Westinghouse in the application of compressed air to useful purposes, which he stated in 1889 should be considered for local uses at Niagara as well as for transmission to Buffalo, as the only system then available and which he would undertake to install successfully, seemed to justify the provision, tentatively made, for the installation of hydraulic prime movers suitable for driving either electric generators or air compressors; thus giving flexibility to the power-plant in its adaptation to the special requirements of the prospective users of Niagara power as they appeared.

[1] See Plan Number IX, Chapter XVII, page 16, Volume II.

During this period very rapid progress was being made in the development of electrical machinery for the production of alternating currents, their transmission to distant points and their control in distribution and use for power and light.

These advances in the electrical science and the art of its application increased the favorable impression received from the studies made both before and after the services of the International Niagara Commission and prepared the management of The Cataract Construction Company to proceed with the electrical side of its enterprise, awaiting further developments in the use of compressed air, while devoting the attention of its engineers to Power-house Number One and its hydro-electric equipment.

ADOPTION OF CENTRAL POWER STATION

The decision of The Cataract Construction Company on December 14, 1891, to adopt a central station for the generation and distribution of electrical energy for lighting and power purposes, locally and for transmission to Buffalo, excited public comment and private preparation.

Here was a corporation

1. with a comprehensive and favorable special charter from the State of New York;
2. openly declaring important results of its intensive examination of the Niagara problem, with the assistance of numerous engineers of those esteemed and distinguished as of the leading scientists of the world;
3. with a list of influential and experienced financiers as stockholders seldom associated in an enterprise of this character;
4. with a subscribed capital and resources comparative in relative magnitude to the Great Falls themselves;
5. already seriously engaged in the construction of discharge tunnels, wheel-pit slot and inlet-canal, as the first section of a hydraulic plant of power development of over 200,000 horsepower, with an estimated earning capacity of not less than $4,000,000 gross per annum and a probable capital expenditure of more than $20,000,000;
6. proposing to generate power in a central station and distribute it for sale on a scale unprecedented, and to adopt electricity for this purpose requiring a performance far exceeding anything that was possible with apparatus then in existence.

INVITATIONS FOR PLANS AND ESTIMATES

The invitations for proposal of electrical equipment were extended only to those organizations that had given evidence of having, or of organizing, a scientific staff competent to design such novel machines as were required, and of ample facilities for their construction. The letters of invitation were as follows:

New York, December 14, 1891.

Electrical Transmission for Local Purposes

Gentlemen:

The board of directors of this company has decided to establish, in connection with the hydraulic works of The Niagara Falls Power Company at Niagara Falls, N. Y., a central station for generation and distribution of electrical energy for lighting and power purposes, locally as hereinafter indicated.

To that end, in behalf of the power company, we invite from you plans and estimates for an electrical installation to be located upon the main canal of that company directly over its turbine wheels (the dynamos to be operated by such turbines), and with an initial capacity of, say, preferably 2500 horse-power each. The power of the turbines will be carried from the wheels to the surface of the ground by vertical shafts. It is for the tops of these vertical shafts that your connections must be indicated to operate the *units* of electrical distribution, based upon the following *present* requirements.

For municipal buildings and street lighting within two miles of the central station—

100 arc lights
100 incandescent lights

For street railway purposes, to be delivered on the trolley within 500 feet of the central station—300 horse-power.

For manufacturing purposes in units delivered to consumers from 25 horse-power to 300 horse-power, within two miles from the central station.

Any estimate should include the furnishing of the central station with the necessary electrical apparatus complete, taking into consideration the possible future extension on the same lines; but no estimate need be made on wiring for the municipal lighting, the requirements above being given simply as a possible aid in the choice of the most convenient units of the efficiency required. The estimate should, however, include the wiring for transmitting the electricity to the motors used in manufacturing establishments. It should also give the kind of motor deemed most effective for the best utilization of transmitted power with the assumed efficiency of the motors, as well as the character of the internal house wiring recommended or required by the system as to safety to life and fire risks.

It may be assumed that the hydraulic work of the power company will be in operation in the early autumn of next year, and the electrical installation should be in place and ready to receive the power at that time.

All estimates should include superintendence of erection and guarantees of efficiency, as follows:

(1) Guarantee of the mechanical efficiency of the whole plant, with deductions in the price to be paid, for each per cent of efficiency guaranteed but not attained;

(2) of permanency of operation, stating the allowance that will have to be made, during the first year of operation, for avoidable repairs and attendance;

(3) stating the reserve plant that must be installed, to insure continuous operation for one year.

Plans should state the number of revolutions required on the turbine shaft for the operation of the dynamos.

In conclusion, we beg to say that we shall be glad to furnish more detailed information upon application at this office.

Very truly yours,
THE CATARACT CONSTRUCTION COMPANY
By
EDWARD D. ADAMS
President

These letters of invitations were sent to the following named designers and manufacturers of electrical machinery in the

UNITED STATES	and	SWITZERLAND
Edison General Electric Company New York		Brown, Boveri & Company Baden
Thomson-Houston Electric Company Boston		Cie. de l'Industrie Electrique Geneva
Westinghouse Electric and Manufacturing Company Pittsburgh		Maschinenfabrik Oerlikon Zurich

The Edison and the Thomson-Houston companies later were merged into the General Electric Company.

It is to be noted that the foregoing letter makes no reference to direct current or alternating current or to the voltage but that these matters as well as the speed are left for recommendation by the bidders. The capacity also is not definitely assigned, but the generators are to be, "say, preferably 2500 horse-power each." Furthermore only "present requirements" for "local purposes" are considered.

CONSULTING ENGINEERS

Early in the year 1892 satisfactory progress had been made in the construction of the several important elements constituting the hydraulic system of the company. The tunnel headings had met, and the work of tunnel lining was approaching closely to the work of tunnel excavation; the inlet-canal and the wheel-pit slot had been under construction for about six months, with satisfactory results; turbine plans had been adopted; preliminary agreements had been made concerning the Buffalo transmission, and designs for the electrical machinery therefor had been received from the Oerlikon Company.

The company's officers considered themselves fortunate in having again secured for this serious investigation the services of Prof. Henry A. Rowland, of the Johns Hopkins University of Baltimore, who was then recognized as the leading physicist of this country. He had already reported on the state of the art of electrical transmission at the request of the financial group in 1889–1890. In 1890, Professor Rowland visited Europe for conference with his scientific friends on the control of the alternating current, its economical generation, transmission, transformation and distribution for use as power at distant points.

A year after the International Niagara Commission had disbanded, in anticipation of the proposals expected, and in response to the letter of invitation of December 14, 1891, The Cataract Construction Company sought the services of European electro-technical advisers with practical experience in design and construction and who were entirely independent of any private interest in the electrical manufacturing business, here or abroad.

After a careful investigation of his experience and ability Prof. George Forbes, F.R.S., of England, was retained in April, 1892, as consulting electrical engineer in addition to Professor Rowland, for scientific counsel in electrical subjects, and supplemental to the mechanical, hydraulic and civil engineers of Europe and this country already occupied in the solution of the great and unique problem The Cataract Construction Company had undertaken to solve.

Professor Forbes was qualified to judge of electrical design and construction by his personal experience in machine design and shop practise. In 1881–1882 he devoted himself, as the chief executive officer of the British Electric Light Company, to the construction of the Gramme and other forms of dynamos. A multipolar type of his design was exhibited at the Electrical Exhibition in Philadelphia in 1884, where, under careful tests, it was reported to have been operated with an exceptionally high efficiency.

His familiarity with electrical machine construction in many countries and his facility of mathematical determination of mechanical and electrical design, gave him special qualifications to serve The Cataract Construction Company, in 1892–1895, as its electrical consulting engineer.

The engagement of Professor Forbes specifically provided for the examination of plans received for the local electrical installation at Niagara and for the Buffalo electrical transmission. He was also to advise the company in regard thereto and upon other electrical matters. In the extension of his contract, it was agreed that Professor Forbes should devote his time to the interest of the company and spend at least six months of each year in the United States.

Professor Forbes had presented to the International Niagara Commission a project, for the electrical part only, of a system of generation with both local and distant distribution of electrical energy for light and power, by polyphase alternating current, generated at 2000 volts, and transmitted, after conversion, at 10,000 volts, with subsequent transformation to a lower pressure in Buffalo for local uses. A premium for this project for distributing power was awarded to him by the commission in February, 1891.

The secretary's records[1] of the scheme presented by Professor Forbes to the International Niagara Commission state that "the project is accompanied by an extremely full and careful memoir, in which the conditions of economical distribution by electricity are discussed. There is also a very detailed estimate of the cost of distribution by the plans proposed." The commission also authorized the statement that they were not convinced that the reasons given by Professor Forbes for an alternating current, in preference to a continuous current system, were sufficient to establish his case.

In his personal explanations before the commission, Professor Forbes stated:

> Of course, in this plan I have had one object before me, to produce designs of the arrangement that seems to be best of those which are absolutely certain to succeed. I have not wished to put into this plan anything which should be experimental. I wished to deal simply with types of machines as we have them at present and of which we are absolutely certain as to the action, and at the same time I would say that if this scheme is adopted I would strongly urge carrying on (simultaneously with the progression of the work according to these lines) certain experimental work which might lead and probably would lead to better results. But I do not wish in my report as to this scheme to put down anything which would not be quite certain.
>
> I have put down only apparatus which we have thoroughly tested and which is on the market and I should like just incidentally to remark that, in making the selection of this, of course, as I suppose every member of the commission is aware, I am in a perfectly independent position, utterly unbiased in favor of any one maker or scheme. I have absolutely no interest either financially or from opinions already expressed in connection with the subject.

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[1] See Appendix E, Volume I.

RESPONSE TO INVITATIONS FOR DESIGN

At the end of nine months, September, 1892, only the foreign companies had replied to the invitation, by submitting designs and estimates. The Oerlikon and the Brown, Boveri companies submitted several projects for an alternating system; and the Geneva company one for a continuous current system for local purposes. A little later, the General Electric Company presented a plan for a direct-current 2500 horse-power machine for local distribution, and subsequently one plan for an alternating and a direct-current machine, each of 2500 horse-power on the shaft of each turbine, and later a completed plan for a 5000 horse-power alternating machine to be used for both local and long-distance purposes.

The foreign companies had the greater experience in long-distance transmission. Professor Forbes preferred the plan presented by the Oerlikon Company to any of the other designs submitted. The foreign designs were, however, not very dissimilar in general character from the plans finally presented by the American companies. When to the cost of foreign machinery, 40 per cent duty and 10 per cent freight were added, the American machinery was very much cheaper. This, and the fact that none of the foreign companies would give satisfactory guarantees against patent suits, may be said to have removed the foreign manufacturers from the competition.

The way was left open, however, for the acquiring of electrical machines from foreign manufacturers until it was clear that satisfactory contracts could be made with an American company. In the matter of turbines it was found best to secure foreign designs and then have the turbines made in America. But it was not at first evident what course would be advisable with regard to the electrical apparatus. It was pointed out that the General Electric Company had been the exponent of the advantages of direct-current machinery and that its manufacture had, up to that period, been practically limited to that type of apparatus and it had, therefore, but little experience in the alternating-current field. Hence the Westinghouse Company was the only large company in America of experience with the alternating system. The possibility of foreign competition was therefore not abandoned until there was ample assurance that it was not needed.

Nothing was heard from the Westinghouse Company until December, 1892, when it announced the preparation of the completed plan for the Niagara work, illustrative machines in operation, and a readiness to submit definite proposals. George Westinghouse, the master of compressed air for power purposes, who in 1889 offered to design and install such a system for the transmission of Niagara power to Buffalo, which he then advised the cataract company to adopt as the only system then available, now changed his recommendation to the polyphase electrical system, so rapid was the advance in the electrical art.

The officers of The Cataract Construction Company, accompanied by their expert advisers, made visits to the factories of both American companies—to that of the Westinghouse Company at Pittsburgh in January, 1893; and in February, 1893, to the General Electric Company's factories at Schenectady and Lynn. Plans for the Niagara installation were shown, typical machines in operation were exhibited, and tests were made by the expert advisers of the cataract company. Both companies had every facility for acquainting themselves with the requirements of the Niagara plant and the benefit of the criticism and suggestions of the company's technical advisers.

In March, 1893, both American companies submitted their complete plans and proposals, each covering

Three 5000 horse-power alternating-current generators, to be placed on the shafts of the three turbines already ordered.

Transformers to step-up the generated current to a high voltage for economical transmission.

A bare copper wire line on poles.

Step-down transformers at the Buffalo end.

The station safety and switching appliances.

Rotary converters, to change alternating to direct current.

Motors for the use of power tenants.

Each of the expert advisers for the cataract company rendered elaborate reports upon each of the designs submitted; Dr. Sellers, the dean of American mechanical engineers, giving particular attention to the mechanical features, Professor Rowland, the renowned physicist, and Professor Forbes, the constructive electrical engineer, reporting upon the electrical efficiency and the state of the engineering arts employed.

Both American companies planned alternating-current polyphase generators; the Westinghouse Company submitting a design of a two-phase system, the General Electric Company of a three-phase system.

Professor Rowland and Dr. Sellers preferred the mechanical design of the Westinghouse Company to that of the General Electric Company and complimented its superior excellence. Professor Forbes preferred the two-phase system of the Westinghouse design instead of the three-phase proposed by the General Electric Company, and stated that the methods proposed by the two American companies were generally identical, with the exception of the difference in phases.

After a careful analysis of the designs submitted and with the approval of its scientific staff the cataract company declined all proposals and proceeded under the guidance of Professor Forbes in the preparation of the plans and designs for a new type of generator.

THE FORBES DESIGN OF GENERATOR

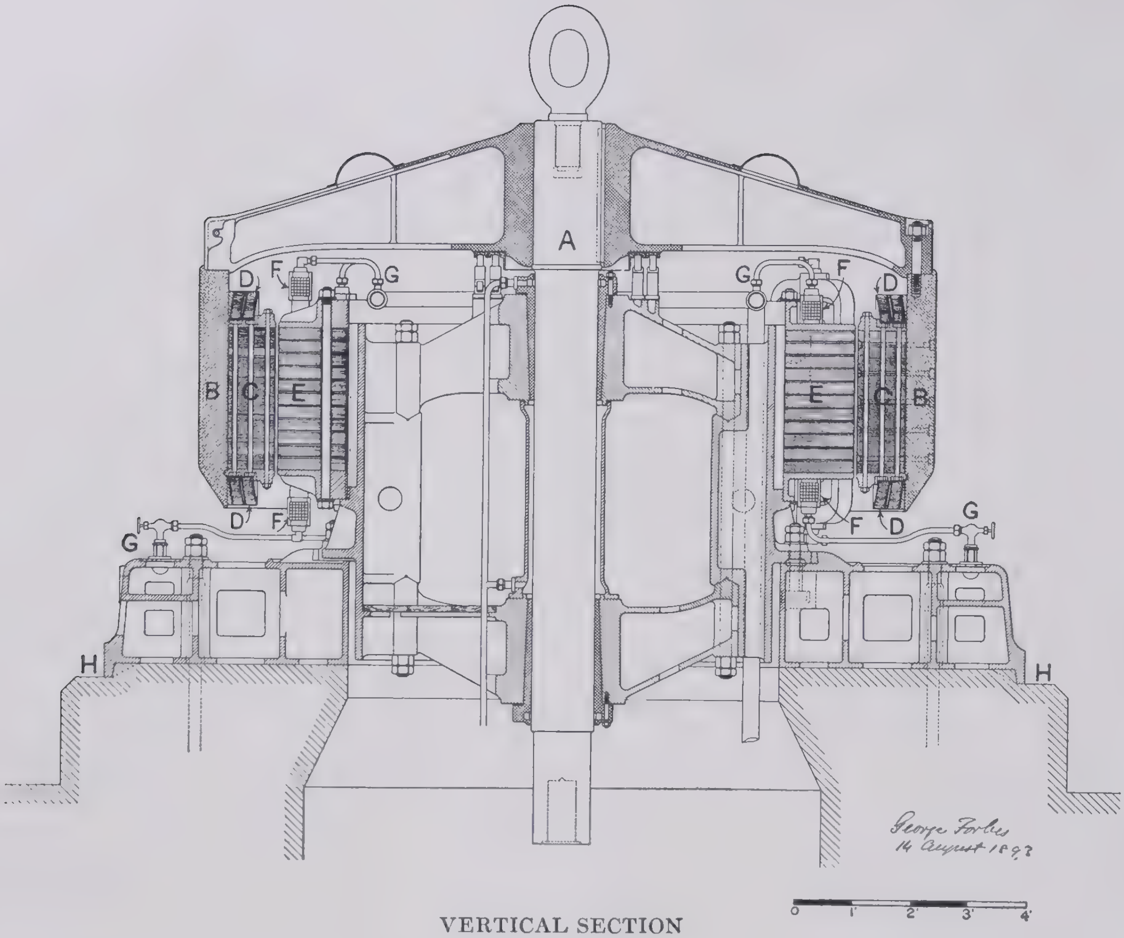
During the period between December 14, 1891, when letters were first issued inviting the submission of designs and proposals to manufacture electrical machinery suitable for the Niagara requirements, and the receipt of plans from the electric companies in March, 1893, Professor Forbes had suggested a design for the proposed generators that differed from the design he submitted to the International Niagara Commission in January, 1891, and that appeared suitable, although somewhat radical, for operation as a single unit, with the hydraulic machinery under construction, and that promised an increase in hydro-electric efficiency with decreased costs.

The delay of the proposers in submitting their completed plans had prompted the management of the cataract company to encourage Professor Forbes to develop his ideas so that the company would be prepared with a design of its own, should those to be submitted by the bidders under the invitation of December 14, 1891, not prove satisfactory to the expert advisers of the cataract company.

Professor Forbes stated to the officers of the company that he was not satisfied with any of the designs presented, because none of them fulfilled the conditions imposed by the designers of the turbine already constructed for use at Niagara, without which features in the generator the speed of the turbines could not be regulated. As he advised that it was advantageous to install generators in which

> the field magnets are external to, and revolve instead of, the armature;
>
> the frequency is not over 16⅔ periods per second; and the working current is generated at low voltage, but can, experimentally at least, be generated at a voltage sufficiently high for economical transmission on the line, without step-up transformers.

With this in view he had designed a machine of which working drawings were then being prepared, not, however, with the object of forcing special details of construction and winding upon any manufacturers, but only with the object of showing them that a dynamo constructed upon these lines would meet all



VERTICAL SECTION

“UMBRELLA” TYPE OF ROTATING FIELD
5000 H-P. ALTERNATOR

HYDRO–ELECTRIC UNIT

designed by Prof. George Forbes, for

THE CATARACT CONSTRUCTION COMPANY

ROTATING ELEMENTS

A Vertical Shaft
B Field Ring
C Field Pole
D Field Winding

STATIONARY ELEMENTS

E Armature Core
F Armature Winding
G Oil System for Insulating and Cooling Armature Coils
H Foundation

2-PHASE 250 REVS. 93 AMPERES
20,000 VOLTS[1] 16.7 PERIODS EACH PHASE

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[1] Capable of working at 10,000 or 5000 volts.

requirements, could be manufactured much more cheaply than any of those proposed, could be readily built by either of the American electrical companies, and was of such simple construction that the majority of its parts could be made by any large mechanical works like those of the I. P. Morris Company, of Philadelphia, where the turbines were then in progress of construction.

The mechanical design proposed that the vertical shaft should drive a great steel ring by means of a conical "driver" having the general shape of an umbrella supporting the ring at its outer circumference. The field poles were within the ring, projecting radially towards the surface of the stationary cylindrical armature. Only by this design could the required angular momentum be obtained from the limited weight allowable.

It should be noted that there was a remonstrance made by the electrical engineers and manufacturers against the adoption of the Forbes design using the revolving external field magnets and the two-phase alternating current at high voltage and only seventeen periods per second.

SPECIAL TYPE OF GENERATOR APPROVED

Lewis B. Stillwell, because of his experience in connection with the final design and construction of the first Niagara machines, as chief electrical engineer of the Westinghouse Company, and of his subsequent responsibility in charge of the operation and maintenance of the ten machines, as electrical director of the Niagara company, was considered especially competent to give an authentic opinion of dynamo designs and performances.

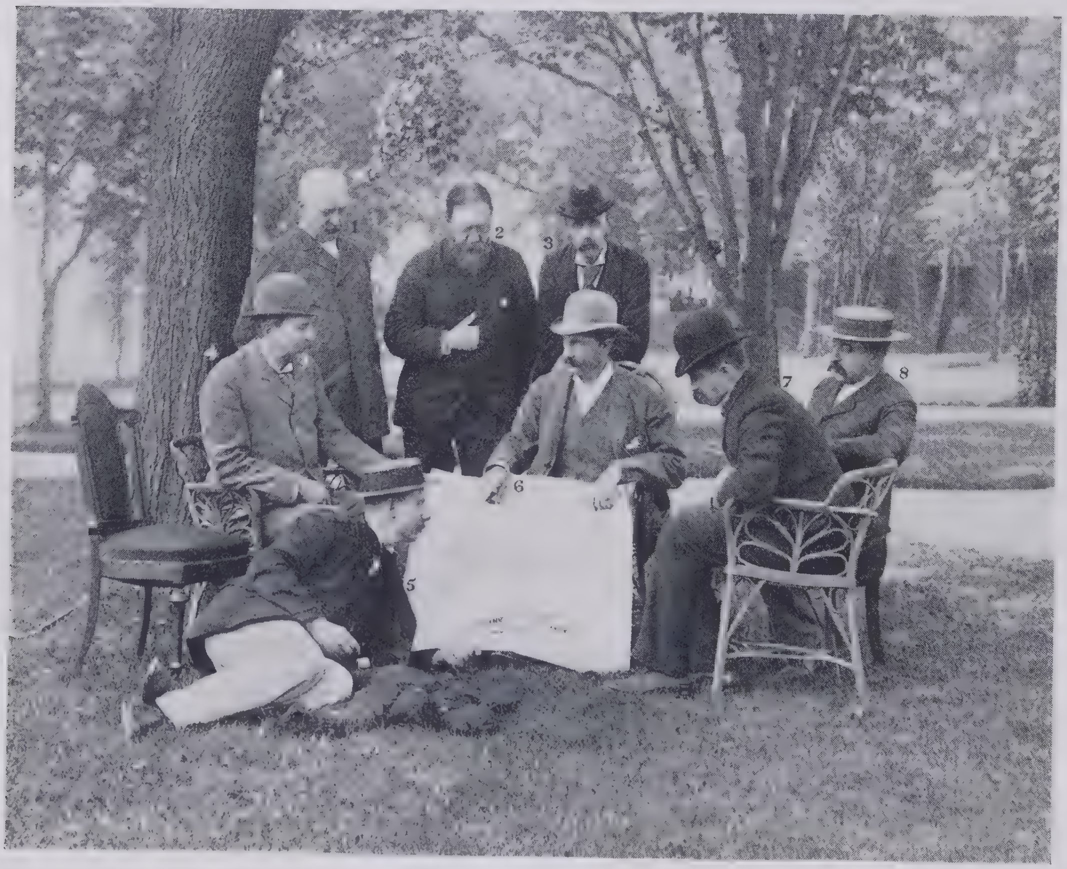
Mr. Stillwell has stated in recent years that the fundamental conception of the design of the first Niagara alternators that were shown at Niagara Falls in the latter part of August, 1893, and there explained in detail to the attending competitors, by the engineers of The Cataract Construction Company, was due to Prof. George Forbes.

He has also expressed the opinion, as regards the construction of the first generators installed by the power company, that the machines actually installed were greatly superior to those originally offered by the Westinghouse Company early in 1893, and for this superiority the engineers of the power company are entitled to much credit.

The type of the machine in its general mechanical features was that proposed by the engineers of The Cataract Construction Company and fully described by Prof. George Forbes in his paper read November, 1893, before the British Institution of Electrical Engineers.

NEW PROPOSALS INVITED

Believing that the company was well informed regarding the latest experience abroad and in this country, and having confidence in its staff of consulting engineers, proposals were invited for the construction of three



Prof. George Forbes

explaining to a group of engineers who visited Niagara Falls when en route from the Chicago Exposition, in 1893, his design for a 5000 horse-power alternator for The Cataract Construction Company

1. *Frank James, District Superintendent of San Francisco Western Union Telegraph Company,*
2. *Sir Wm. Preece, F.R.S., Head of the British Post Office Telegraph,*
3. *Lord Moulton, F.R.S., Judicial Lord,*
4. *Col. Robert C. Clowry, General Superintendent at Chicago, Later President and General Manager, Western Union Telegraph Company,*
5. *Lieut. A. J. Saltren-Willett, R.E.,*
6. *Prof. George Forbes, F.R.S.,*
7. *Colonel Holden, R.E., Sometime Head of Woolwich Arsenal,*
8. *Major Bagallay, R.E.*

dynamos of the Forbes "umbrella" type of 5000 horse-power each, with the necessary auxiliary apparatus. The formal invitation for bids was issued to the two American constructors, the General Electric Company and the Westinghouse Electric and Manufacturing Company, in letters of invitation reading as follows:

New York, August 10, 1893.

Gentlemen:

The preliminary design of the generator adapted to the electrical system deemed most advantageous in our case is now sufficiently elaborated to enable us to present the entire scheme for your careful consideration, and in such form as will enable you to make tenders for what you require.

That you may fully understand what we want, we desire that you send to Niagara Falls at your earliest convenience on or after the 14th inst., a competent representative or representatives to receive explanations, and be furnished then with the necessary drawings and documents to enable you to make an intelligent study of this subject. Professor Forbes and Dr. Sellers will be at Niagara for the purpose of consultation in regard to the electrical and mechanical features of the design. *Our reason for not furnishing and transmitting to you complete working drawings upon which you could bid is that you may be able to modify the design to adapt it to your machine tool and your mode of manufacture. Any alterations that you may propose in the design will be carefully considered, and if acceptable, will be appreciated in awarding the contract.* We desire your offer to be accompanied by guarantee as to quality of workmanship and efficiency of operation. Time of completion and installation will be considered an important factor in award of contract.

Very truly yours,

THE CATARACT CONSTRUCTION COMPANY
by Edward Dean Adams
President

ALTERNATING CURRENT OFFICIALLY ADOPTED

The cataract company, now for the first time, specified the alternating-current system. The long controversy between the direct and alternating current systems had been officially terminated by action of the directors of the cataract company on May 6, 1893, which is one of the red letter days in the history of The Niagara Falls Power Company and of the electrical industry as well. Many references to the "AC-DC" controversy and the claims made for the two systems have been recounted in other chapters.

As there had been a difference of opinion on the part of consulting engineers of The Cataract Construction Company as to the relative commerical value of the direct and the alternating current systems and as demonstrations were rapidly removing objections to the alternating current, the determination of the type of current to be generated was left until the last moment in order to have the guidance of the latest foreign and home experience. In the meantime The Cataract Construction Company proceeded with the preparation of its plans for hydraulic turbines, with units of at least 5000 horse-power, expecting, when the main electrical questions involved were determined, to call for proposals for the construction of electrical generators of similar speed and power, to be combined directly with the hydraulic turbines as single units on single perpendicular shafts.

Two years, 1891–1893, intervened between the issuing of the report of the International Niagara Commission and the official adoption of polyphase alternating-current apparatus. The success of the Frankfort-Lauffen transmission and the larger number of alternating plants for lighting and power designed and installed by Swiss engineers justified their earlier predictions by an era of progressive achievement.

In the United States the newly formed General Electric Company changed from opposition to advocacy and took up actively the production of alternating-current apparatus. There was continued extension of plants of this type for lighting, both in their number and their size. The successful operation of the Westinghouse 4000-volt transmission system for lighting at Portland, Oregon, and of 3000 volts for power at Telluride, and of 10,000 volts for lighting in southern California were all important steps in establishing confidence in the dependability of electrical operation and the capability of the alternating current. The letting of the contract for lighting the World's Columbian Exposition at Chicago, by alternating current after an intensely active competition, and at a price approximately a million dollars less (on a total of about five million dollars) than the proposal for a direct-current system gave alternating current new recognition as this was the largest electrical installation ever undertaken. The polyphase exhibit at the fair, a miniature of the system which Westinghouse planned for Niagara, has been described in the preceding chapter, page 193.

The formal decision in favor of alternating current by The Cataract Construction Company and the opening of the World's Fair occurred in the same month, May, 1893.

Although alternating current had few advocates in 1890, the three technical advisers of the company finally united in recommending the alternating-current system. Professor Forbes for some years had consistently recommended it; Professor Rowland, when first retained in 1889, advocated the continuous current system, but after thorough study of the matter and practical demonstrations, united with Professor Forbes in its recommendation and Dr. Sellers recommended it for its economy and utility for the company's purposes.

The outstanding and persistent advocate of direct current among those who were associated with the Niagara enterprise was Lord Kelvin. On May 1, 1893, he cabled:

> Trust you avoid gigantic mistake of adoption alternating current.

The interesting story of his change of attitude expressed when visiting the plant after several years of operation is told elsewhere.[1]

PHASES: TWO OR THREE?

The selection of the polyphase system made necessary a choice between the two-phase and three-phase circuits. While in a general sense they were equivalent, the characteristics of each fitted it to meet certain conditions better than the other. There was little experience to serve as precedent and one or the other was advocated depending upon the particular experience of the adviser or the relative importance assigned to the several requirements which it was assumed the new plant would be called upon to meet.

The Westinghouse Company proposed two-phase generators. The General Electric Company recommended three-phase, but stated that they would supply two-phase apparatus if it were specified.

Of the company's technical advisers, Professor Forbes and Dr. Sellers strongly favored the use of the two-phase system, while Professor Rowland, in his final report, stated that the advantages and the disadvantages of the two systems (two and three-phase) seemed about equal. Professor Forbes reported that on the whole he had a decided preference for the two-phase system, although he was quite aware that the Niagara company should also be able to work either on the three-phase or the single-phase system.

The counsel of other than the company's regular expert advisers gave a weight of authority in favor of the two-phase system. Confirming the advice of Professor Forbes and Dr. Sellers in this regard were Nikola Tesla, whose induction motor represented his preference for alternating current; Colonel Turrettini, who cabled:

> In my opinion two-phase system unites all advantages of the three-phase and renders dynamos more simple

and Dr. J. A Fleming, who cabled:

> Prefer two-phase

and wrote, March 26, 1893:

> I consider your commercial necessities will best be met at the place of consumption by distributing a direct current on a three-wire system which is derived from two-phase motor generators which are driven by a two-phase current supplied from the distant generators.

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[1] Chapter XXVII.

Dr. J. Hopkinson, F. R. S., of London, though from a theoretical point of view preferring the three-phase to the two-phase, stated as his conclusion that there was not very great advantage in either of these systems over the other, "certainly no such advantage as would induce me, in dealing with a capable and responsible contractor, to thrust the one system upon him if he had a strong preference for the other."

The Oerlikon Company, of Switzerland, with their wide experience, favored three-phase, but in their project proposed both three-phase and two-phase, (and offered to adopt either).

C. E. L. Brown, of Switzerland, who had large experience in polyphase currents, and much to do with the three-phase Frankfort transmission, stated his belief that

> In future the two-phase current will take the lead where combined light and power distribution is required, while the three-phase current may be used for the simple power transmission and distribution.

The advantages of the two-phase system where there was lighting or other single-phase load, together with the probability that there would be considerable single-phase load upon the Niagara plant, led to the adoption of two-phase generators.

PERIODICITY OR CYCLES PER SECOND

The word "power" in the incorporation title of The Niagara Falls Power Company, indicated the purpose of the incorporators, as explained in their charter, to develop power for use in manufacturing and transportation at and in the vicinity of Niagara Falls and Buffalo, and beyond.

While light was considered as one form of the proposed electrical power development, its use by the 10,000 inhabitants of Niagara was recognized as of relatively small importance.

There was also then but little use for power in Niagara, as there were but few industries there, whereas in Buffalo there were 250,000 inhabitants widely engaged in manufacturing and who had recently expressed their anxiety for Niagara power by offering a cash bonus of $100,000 if it were brought to their city.

In the use of alternating current, it was found that a comparatively low rate of alternation or periodicity favored the use of the current in larger motors and for the operation of rotary converters for changing alternating current into direct current for the operation of street railways and for other special purposes. An increase in the number of cycles per second made the current less desirable for power purposes although the higher frequencies were more suitable for incandescent and arc lighting.

The Westinghouse Company adopted, in the autumn of 1892, two standard frequencies of 60 cycles per second for lighting and 30 cycles per second where power in large units and rotary converters were to be used.

In January, 1893, Dr. Sellers and Professor Rowland tested the effects of lower frequencies on lamps, in the works of the Westinghouse Company at Pittsburgh, with its engineers. It was reported that at 25 cycles per second incandescent lamps did not show objectionable fluctuations but that a further lowering of the frequency soon caused objectionable flickering.

The General Electric Company recommended 41.6 cycles per second, at which frequency both arc and incandescent lights were found most satisfactory.

Professor Forbes, who understood the Niagara company's desire to equip its works for long-distance transmission of power, first expressed a decided preference for 8⅓ cycles per second; but in the summer of 1893, when he submitted his suggestions to the cataract company's engineers, and their joint dynamo design was shown to intruding bidders at Niagara, it was particularly noted that the design provided for a frequency of not over 16⅔ cycles per second, this increase in frequency then appearing to him to be necessary for a sound mechanical design.

The board of directors of The Cataract Construction Company had instructed its officers to bring the details of the specifications as close as possible to the desires of its technical advisers, combined with sufficiency of guarantees from the manufacturers.

The attitude of the Westinghouse engineers upon the subject of current frequency was shown by their assurance to their president, September 27, 1893:

> As regards frequency, we advise 4000 alternations per minute (33⅓ cycles per second), but will build for 2000 (16⅔ cycles) provided that no insuperable difficulty presents itself when we come to work out the complete plan of the generator.

The officers of The Cataract Construction Company declined to award the contract under such conditions unless the manufacturers guaranteed the efficiency of operation.

In the course of the negotiations, there was a dinner conference of the principal representatives of The Cataract Construction Company and of the Westinghouse Electric and Manufacturing Company, at the Union League Club of New York, in October, at which the details of the proposed contract were discussed at length, with the definite result, regarding frequency, that the construction company insisted upon 16⅔ cycles and a guarantee of efficiency in operation, while the Westinghouse Company expressed an unwillingness to give its guarantee upon any frequency less than 30 cycles.

Before the diners separated, President Adams of The Cataract Construction Company sought a personal conference with Mr. Stillwell, the engineer of the Westinghouse Company in charge of the Niagara negotiations, at which a question substantially as follows was asked:

> Can the Westinghouse Company build a satisfactory alternator which would deliver current at 25 cycles, the efficiency of which would be guaranteed by that company?

Mr. Stillwell answered, in effect, that, as requested, the subject would be carefully reviewed by his company.

The speed of the hydraulic turbines had already been fixed at 250 revolutions per minute. Professor Forbes proposed that the generators should have 8 poles which would produce 2000 alternations per minute, or 16⅔ cycles per second; the Westinghouse Company recommended 16 poles and 4000 alternations or 33⅓ cycles, which most nearly approximated the 30 cycles which it proposed as a standard as was possible to obtain at a speed of 250 revolutions. It was finally agreed that there should be 12 poles and the result was 3000 alternations or 25 cycles, this being the lowest frequency for which the Westinghouse Company would guarantee sound mechanical design. This Niagara frequency was soon adopted by many other power plants.

ACCEPTANCE OF WESTINGHOUSE PROPOSAL

At a conference between the principal officers of The Cataract Construction Company, and the Westinghouse Company, early in September, Mr. Westinghouse agreed that his company would submit tenders for dynamos embodying such features of the Forbes design as it might deem practicable, but with such modifications as the engineers of his company should recommend.

Proposals were received in October, 1893, from the Westinghouse and General Electric companies which had been invited to bid on the construction of the three alternators incorporating the mechanical features of the Forbes design.

These proposals were referred to the company's advisers for examination and recommendation for action.

Dr. Sellers and Professor Rowland preferred the design of the Westinghouse machine on account of its mechanical excellence; they agreed in considering the machinery turned out at the Westinghouse Company's works as superior to that made at the General Electric Company's works. Professor Forbes considered the machinery turned out at the Westinghouse Company to be of superior quality.

The report of the engineering experts was as follows:

New York, October, 6, 1893.

To the Board of Directors
of The Cataract Construction Company

Gentlemen:

We have had before us the various bids and propositions for our first generators.

We have aimed at securing a machine as far in the front ranks of practical electrical development as is consistent with the commercial considerations which ought to guide the enterprise combined with such a guarantee from the manufacturers as shall certainly secure efficiency of operation.

As a result of our deliberations we have come to the conclusion that out of the various bids which have been submitted to us your interest will best be served by accepting the offer of the Westinghouse Electric and Manufacturing Company, *and instructing your officers to bring the details of the specifications as close as possible to the desires of your technical advisers combined with sufficiency of guarantee from the manufacturers.*

We have the honor to remain, Gentlemen,

Your obedient servants
George Forbes
Coleman Sellers
Th. Turrettini
DeCourcy May

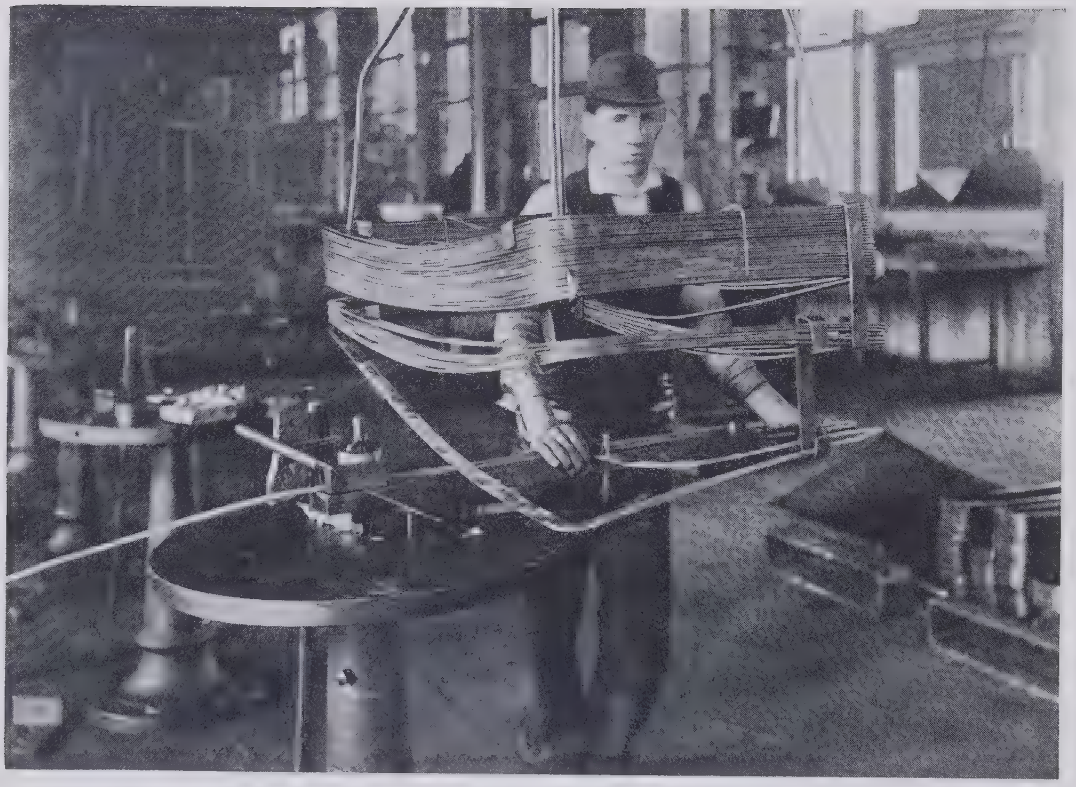
Professor Forbes stated in part, in reply to inquiries by the directors of the company, in session, October 12, 1893,

that he had been visited at Niagara by representatives of the different electrical and other companies and that equal facilities for examination and explanation of his design and of the purposes of the company had been afforded to the representatives of each of the companies referred to.

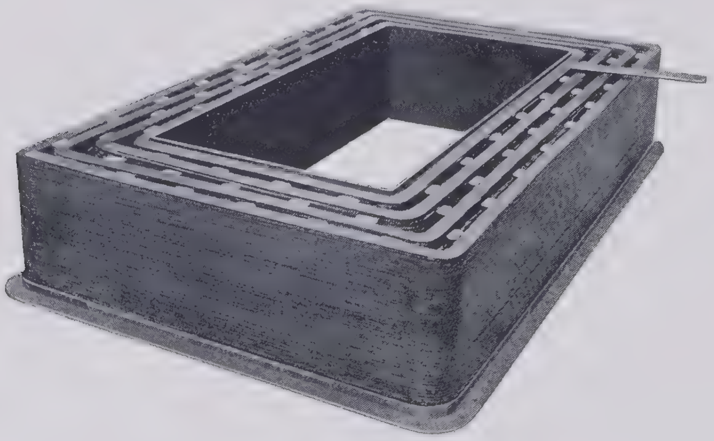
The directors adopted the recommendation of the company's technical advisers, and authorized the officers to contract with the Westinghouse Electric and Manufacturing Company for three dynamos of 5000 horse-power each, under a contract in form, and containing guarantees, satisfactory to the legal and technical advisers of the company.

PATENTS

The cataract company management appreciated that if a foreign design should be selected for the manufacture of the Niagara electrical machinery, The Niagara Falls Power Company would be subjected to attack by American companies for infringement of their patents. It had been ascertained by refusals that none of the foreign manufacturers were willing to give proper guarantees in regard to infringements of United States patents. In order to take all precautions from expert advisers in regard to the patent



Copper Strap Being Wound on Edge to Form Part of Field Coil for 5000 Horse-power Generator, Power-house Number One



Field Coil of 5000 Horse-power Generators, Power-house Number One

Four concentric coils of thin copper strap wound on edge; asbestos and mica insulation; air spaces between coils for ventilation situation affecting generators, Frederick H. Betts, an expert patent lawyer of New York, was consulted and submitted a report on the specific questions asked, under date of March 11, 1893, writing as follows:

> In my opinion the claims of Mr. Bradley (General Electric Company) are of such a character, and the claims of Mr. Tesla (Westinghouse Electric Company) are of such a character that, in the purchase or use of alternating current, multiphase generators and motors from the owners of either of those patents, you are almost certain to be brought into conflict with the claims of the owners of the other patents. It is difficult to see any escape from this probable position. . . . In the construction, purchase or use of apparatus of these classes, you must, therefore, protect yourselves, as far as possible, by strong guarantees on the part of the parties dealing with you.

After reading Mr. Betts' report and referring to the converters proposed by the General Electric and Westinghouse companies for changing the alternating current to the direct current, Professor Forbes states:

> With regard to the patent question, I may say that so far as I have been able to examine the position up to the present, it seems probable that the General Electric Company cannot supply us with this machinery (A.C.-D.C. commutator) without infringing the Tesla patents owned by the Westinghouse Company, and that the Westinghouse Company cannot supply us with this machinery without infringing the patent of Elihu Thomson for an induction armature owned by the General Electric Company.

Among the patent plates upon the generators, a number bear the names of George Forbes, May 1, 1894, and Coleman Sellers, June 5, 1894, one patent each.

GUARANTEES

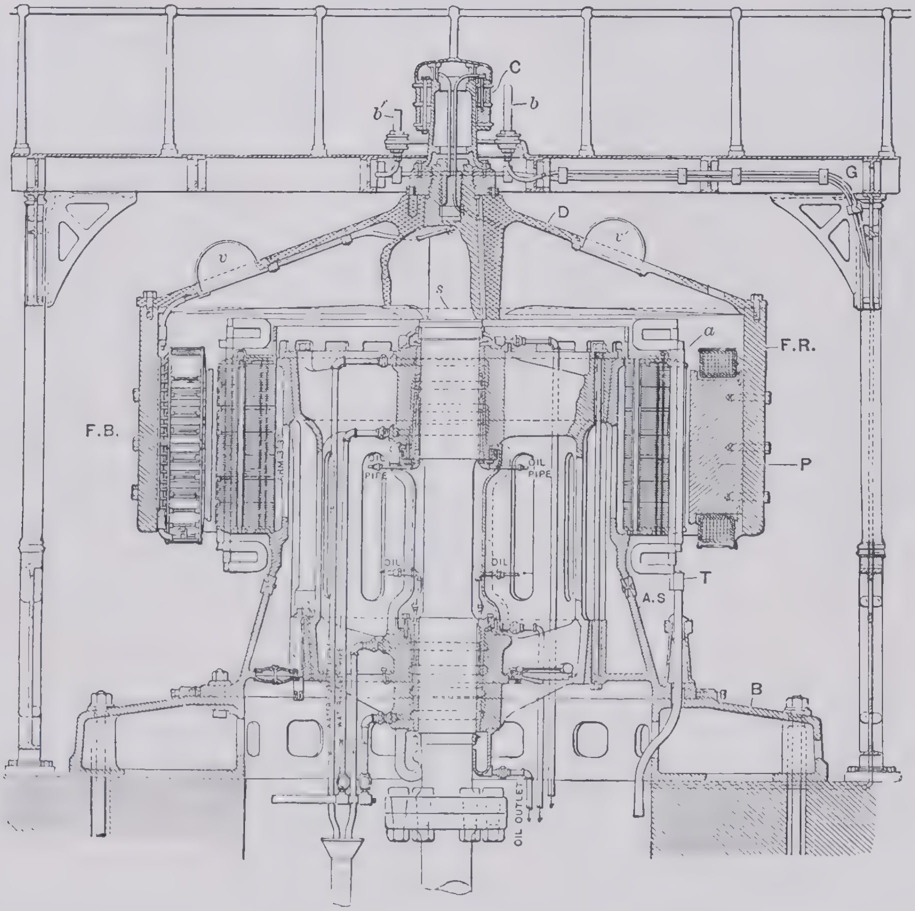
The following is a condensed statement of guarantees given by the Westinghouse Electric and Manufacturing Company in its contract for dynamos of October 26, 1893:

> An output of 5000 electrical horse-power at an effective potential of from 2000 to 2400 volts when driven at a speed of 250 revolutions per minute; the maximum rise of temperature to which the insulation of armature or fields shall be subjected, not to exceed forty (40) degrees Centigrade above the temperature of the surrounding air; generators to be interchangeable; the total electric and magnetic losses in each generator not to exceed 2½ per cent of its rated output; the field magnet ring to be of forged nickel steel without weld, and to have a tensile strength of 75,000 pounds per square inch and not less than 25 per cent elongation in a specimen 2 inches long between measuring points and ½ inch in diameter; the efficiency of transformers under full load to exceed 97½ per cent; the maximum rise of temperature of the oil above the temperature of the surrounding air not to exceed 80 degrees Centigrade; the efficiency of the two-phase motors of the synchronous type and of the alternating-current motors of the rotary field type, to be approximately equal to the efficiency of the direct-current motors of corresponding sizes.

The contract contained the following further guarantees:

> We will guarantee the efficiency, temperature, and output as stated respectively above, and we will guarantee all the apparatus to be free from defects of labor and material, and to be of superior strength and design.

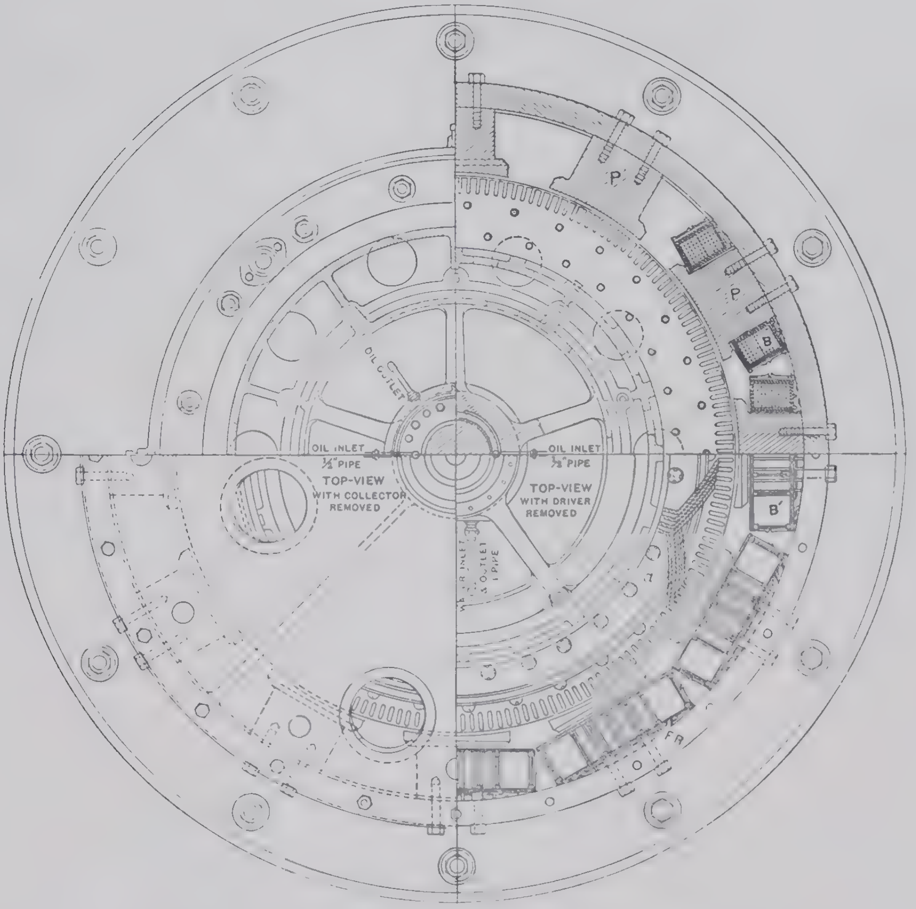
Vertical Section



First 5000 Horse-power Niagara Alternator as Designed and Installed by the Westinghouse Electric and Manufacturing Company

As to the patents, the Westinghouse Electric and Manufacturing Company will, at its own cost and expense defend any and all suit or suits that may be instituted by any party against you or against The Niagara Falls Power Company or any other company for whom you may install our apparatus, for the alleged infringement shall consist in whole or in part in the use of any apparatus, machinery, or devices, or parts thereof, manufactured and sold by it to you for which you shall have made all payments then due, provided that reasonable notice of the institution of such suit or suits be given in writing by you to the company and that you shall permit the company through its counsel to defend same, and shall give it all needed information, assistance and authority to enable it to do so; and thereupon, in case of an award or damages in such suit or suits the company shall pay such award, but the company shall not be bound to defend any suit or suits, nor to pay any damages therein, when the same shall arise by reason of the use of parts not furnished by the company.

Horizontal Section

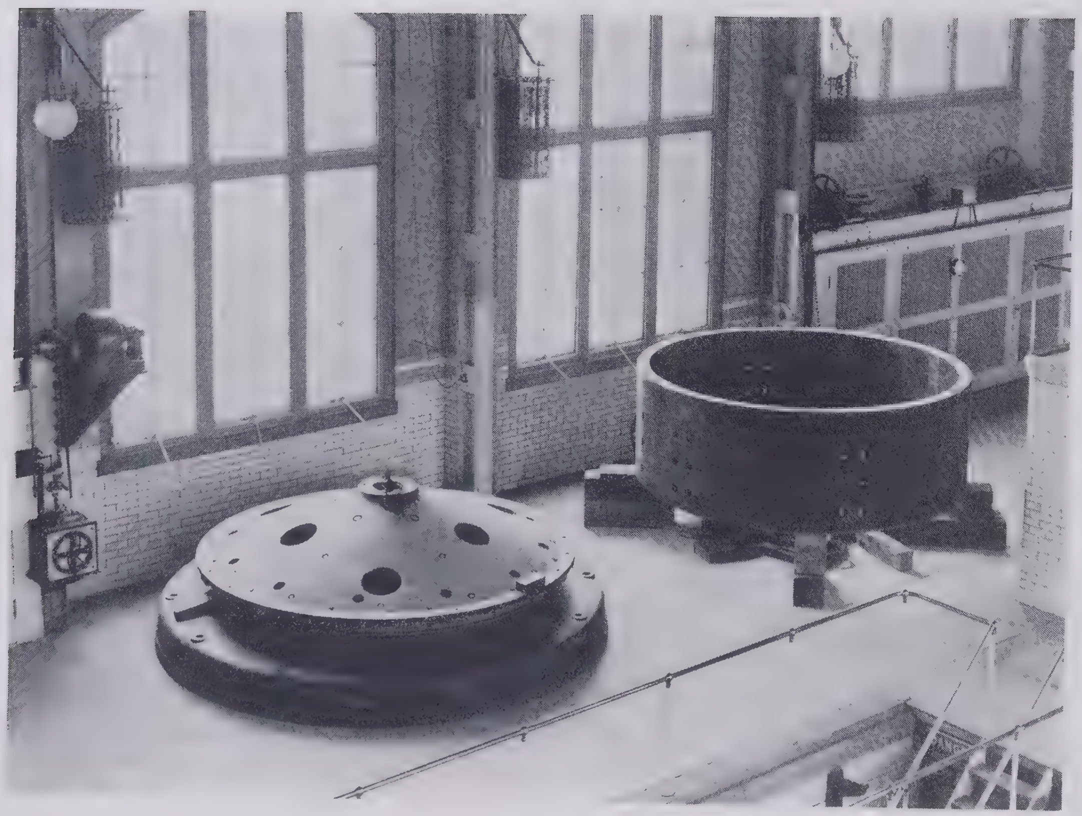


First 5000 Horse-power Niagara Alternator as Designed and Installed by the Westinghouse Electric and Manufacturing Company

CONTRACT ANNOUNCED

The contract, with guarantee, was signed October 27, 1893, and the official statement of the parties thereto was at once made public, to wit:

After protracted and exhaustive examination of many plans submitted by various electrical companies in America and Europe, The Niagara Falls Power Company has awarded to the Westinghouse Company of Pittsburgh, Pennsylvania, a contract covering the construction and installation of three alternating-current dynamos of 5000



Field Ring, 5000 Horse-power Generator, Power-house Number One

Field Ring of Generators with Two
Poles and Coils

horse-power each after designs originating with the engineers of The Cataract Construction Company and especially adapted to the particular requirements of the hydraulic installation of The Niagara Falls Power Company. The system adopted involves the use of two-phase current with a frequency of 25 periods per second generated at a voltage of 2000 and the use of transformers for long-distance transmission at higher tension.

INSTALLATION OF GENERATORS[1]

In September, 1895, two generators had been installed and tested, and the third generator was in process of construction.

Instrument Panel for 5000 Horse-power Generator
Power-house Number One, 1896

The Westinghouse Company reported at that period:

> We have made several minor modifications of the plans laid before us at the time the contract was completed. These modifications have in all cases received the approval of Dr. Coleman Sellers, chief engineer of The Niagara Falls Power Company, and it is believed to have without exception resulted in improvement of the original design.
>
> The switching devices, indicating and measuring instruments, bus-bars and other auxiliary apparatus, have been designed and constructed on lines departing radically from our usual practise. The conditions of the problem presented especially as regards the magnitude of the amount of power to be dealt with, have been so far beyond all

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[1] See Appendix M, Volume II, for detailed description of generators.

precedent that it has been necessary to design a considerable amount of new apparatus. The general organization of the cables, switches and measuring instruments, differs materially from anything of the kind hitherto installed elsewhere.

Nearly every device used differs from what has hitherto been our standard practise.

Among novel features of importance we may mention the use of compressed air to operate the switching devices, the construction of the 5000 horse-power switches, and the construction of the bus-bars.

REPORTS TO STOCKHOLDERS

The evolution in ideas and plans and the progress of the Niagara enterprise may be found in the circulars issued from time to time to the stockholders. In such a circular dated February 15, 1893, eight months before the awarding of the contract for first generators, it was stated that the directors of The Cataract Construction Company had unanimously decided that the best interests of the project would require the expenditure of $1,200,000 during the year ending April 1, 1894, and the following explanation was made:

> While the directors are of the opinion that in a work of this novel character, frequently calling for change of plan, it is not desirable to forecast with too great particularity the details of the proposed expenditure, they are prepared to make use of this sum in the extension of wheel-pit, additional development of hydraulic power, the construction of a power-house, with its appurtenances, and the construction of a line of transmission for manufacturers on the company's property, as well as some eighteen miles to Buffalo, where abundant opportunity and demand for Niagara power has already developed.
>
> On every side inquiries and requests for power on favorable terms have been made to such an extent as to justify the belief that as soon as water has begun to flow through the tunnel, in or before the month of May, 1893, a quick and urgent demand for this power, both hydraulic and electrical, will show itself at Niagara, as well as at Buffalo, but undoubtedly it is from this great city, now employing more than 50,000 horse-power, that the most urgent demand will come for immediate use. To anticipate this demand, so as to meet it when made, seems the part of wisdom, and it has been determined to include this great project of long-distance transmission within the present purposes, subject to such change of plan as may be found to be for the best interests of yourselves and the enterprise.
>
> In this place it may properly be said that the raising of this money is to provide for new and additional facilities and installations, rather than to make good deficiencies in the original estimate of 1890. The rapid advance of the electrical art since that date has compelled such changes as to make difficult and unwise any close adherence to the original plan.

The Cataract Construction Company reported to its stockholders, December 15, 1896:

> The present electrical installation comprises three dynamos, each of 5000 electrical horse-power, of which one should be kept as a reserve; but the demand has made such

reservation impossible and the contracts already made for 15,825 electrical horse-power exceed not only the prudent but the actual capacity of these works, which require immediate extension, with every prospect of prompt and profitable employment. . .

The course which should be pursued may be indicated by the statement that, in the opinion of the board of directors (supported by subscriptions from their own number), this enterprise has never promised so well as now, either in practical operations or financial results.

Since work was begun in 1890, no interest in The Cataract Construction Company is known to have been sold for less than par. Notwithstanding at least four financial crises, and other influences deterring the establishment of new industries requiring power. Considering these general and well-known adverse conditions, coincident almost with its life, the wonder is that this company has steadily progressed, and, as above indicated, has almost reached the point of self-support. Under such conditions, and in view of the necessarily experimental character of the work, it would have been folly at any earlier date to seek to provide for an installation larger than necessary to demonstrate that this enterprise can accomplish real work and promise real profits, such as now can be expected after January 1, 1898.

This promise is based upon the proposed completion of the installation up to the point at which it will be possible to develop at Niagara for commercial requirements 35,000 available electrical horse-power from eight dynamos, each of 5000 horse-power (one being kept in reserve), and to complete the Buffalo transmission line, so that it will be sufficient to deliver in Buffalo 10,000 electrical horse-power as required by the municipal franchise.

Such installation it is estimated will be sufficient, and it is expected, promptly to produce a net income of over $600,000, against which the bonded interest will not exceed $450,000 (after funding all interest up to January 2, 1898), leaving a probable dividend fund sufficient for 5 per cent upon the stock, and all the vast remaining lands, properties and the rights of the company for future development.

The proposed extension involves doubling the present capacity of the transmission line to Buffalo which is now delivering 1000 electrical horse-power; the extension of the wheel-pit for its full length, so as to have capacity in all for ten 5000 horse-power turbines and dynamos; the installation of seven 5000 horse-power turbines and dynamos, in addition to the three now in operation; and the extension of the power-house to cover the new installation. Such an extension of the wheel-pit is about one third completed; the right-of-way from Niagara Falls to Buffalo is complete; the pole-line already has a pole and cross-arm capacity of 20,000 electrical horse-power, with copper conductors in place for 5000 electrical horse-power. Upon definite proposals already received, the entire installation above described can be progressively completed before April 1, 1898, with the proceeds of the subscription of $2,000,000 now invited, and already largely taken.

The Cataract Construction Company having surrendered its control of the Niagara companies preparatory to liquidation, after its ten-year period of construction, and its officers and directors having assumed the management as stockholders and directors of The Niagara Falls Power Company announced, November 16, 1899:

> that early in 1900, ten 5000 horse-power turbines and dynamos will be in operation in the power-house (Number One) at Niagara Falls, extended and completed as anticipated upon December 15, 1896.
>
> Upon the basis of existing arrangements, and without any new contracts, the estimated net income (one dynamo being held as a reserve), will exceed the annual fixed charges.
>
> The limit of the present power-house and the present wheel-pit upon the west side of the canal has been reached, and additional turbines and dynamos can be established only by the construction of an additional wheel-pit, and an additional power-house, for which a site upon the east side of the canal, approved by the professional advisers of the company, has been adopted by the board of directors.
>
> The cost of the wheel-pit, connecting tunnels and power-house and of the eleven turbines and dynamos, will be approximately $3,000,000, which sum, when expended, will substantially double the present income-producing power of the electric plant. That the additional power produced by this new construction will find demand at remunerative rates and within a reasonable period is the belief of every member of the board of directors, which unanimously has resolved to proceed with the execution of the work as above indicated.

ADDITIONAL CONTRACTS FOR ELECTRICAL EQUIPMENT

While the Westinghouse Company secured the three several contracts that comprised the entire equipment of ten units aggregating 50,000 horse-power, of Power-house Number One, the General Electric Company was at that time awarded the contracts for the design and construction of the transformer station for the Buffalo transmission, the rotary converter installation at the Buffalo terminal, and all apparatus for the Cataract Power and Conduit Company of Buffalo and the Buffalo General Electric Company.

Soon after the 5000 horse-power units numbered one to ten in Power-house Number One had been placed in commercial operation, in May, 1900, invitations were extended by The Cataract Construction Company for proposals for the design and construction of alternators for Power-house Number Two, of similar characteristics to those already in operation in Power-house Number One.

Successive contracts were awarded to the General Electric Company comprising the entire installation of eleven alternators of 5500 horse-power each, of which six, numbered 11 to 16, were of the external revolving field type, similar to the ten units in Power-house Number One, and five, numbered 17 to 21, were of the internal revolving field type.

All these machines were constructed with improved ventilation and regulation, and the last five without the heavy revolving nickel-steel forged ring previously used in the sixteen machines already in operation.

Other improvements were adopted at the suggestions of William LeRoy Emmet, engineer of the General Electric Company, that were important advances in the art of electric development and distribution.

In the Canadian power-house the first five alternators were designed and built by the General Electric Company. They were rated at 10,000 horse-power each, and were placed in commercial operation in 1905–1906. The remaining five machines in that plant, designed and built by the Canadian Westinghouse Company, Limited, of Hamilton, Ontario, were rated at 12,500 horse-power each, and were gradually installed as the demand increased for their electrical product. The units in all of the three plants operate at 250 revolutions per minute.

Further data and details of reconstruction are contained in other chapters, notably those dealing with turbines and power-houses, and their appendices.

THE POLYPHASE SYSTEM IN OPERATION

The various electrical "systems" employed for arc lighting, for incandescent lighting by direct current and by alternating current, for railway operation and for motor service, which were employed in the early nineties have been described in Chapter XXI. The generators were of many kinds and of small size. Each kind of service involved its own generators and circuits. There was no common universal large scale system until the Niagara plant began operation.

The new general system of electric power service by polyphase alternating current inaugurated at Niagara was described in a lecture by Charles F. Scott at the Engineers' Club of Philadelphia, April 17, 1897, who presented the accompanying diagram which shows the service then rendered by The Niagara Falls Power Company, and illustrates the variety of ways in which electric power can be supplied by the alternating-current polyphase system from a single source.

Professor Scott has recently made the following explanatory statement:

> The first three applications near the top of the diagram show an electric railway, an arc lighting system and an incandescent lighting system. Each of these had required it own type of generator, driven by an engine. In the diagram the original lighting station is still operating, although the old lighting generators are no longer operated by a steam engine but by a motor receiving power from the hydro-electric plant. This is an interesting transition.
>
> The diagram prepared before the plant had been in operation two years shows a very great variety of electrical conversion and transformation. There is direct current supplied as constant current and also at constant voltage, the value of the constant voltage differing in different installations, and also direct current at variable voltage

adjustable over different ranges to meet the varying requirements of electrochemical loads. There is alternating current at several constant voltages, also at variable voltage. There is transformation from two-phase to three-phase and transmission at high voltage. Current is used for ordinary power purposes, for arc lighting and incandescent lighting and for various heating and electrochemical processes, employing resistance furnaces, arc heating and electrolytic reactions of various kinds.

All these seem very commonplace today, but then it was a new thing, and Niagara was not only the birthplace of hydro-electric power, but *it was the first large scale example of a comprehensive electrical power system supplying power of all kinds from one circuit.*

The polyphase power-plant at Niagara was in 1895 the Electrical Wonder of the World. It was the pioneer, others followed and today practically all of the electrical power in the world is produced and transmitted as polyphase alternating current.

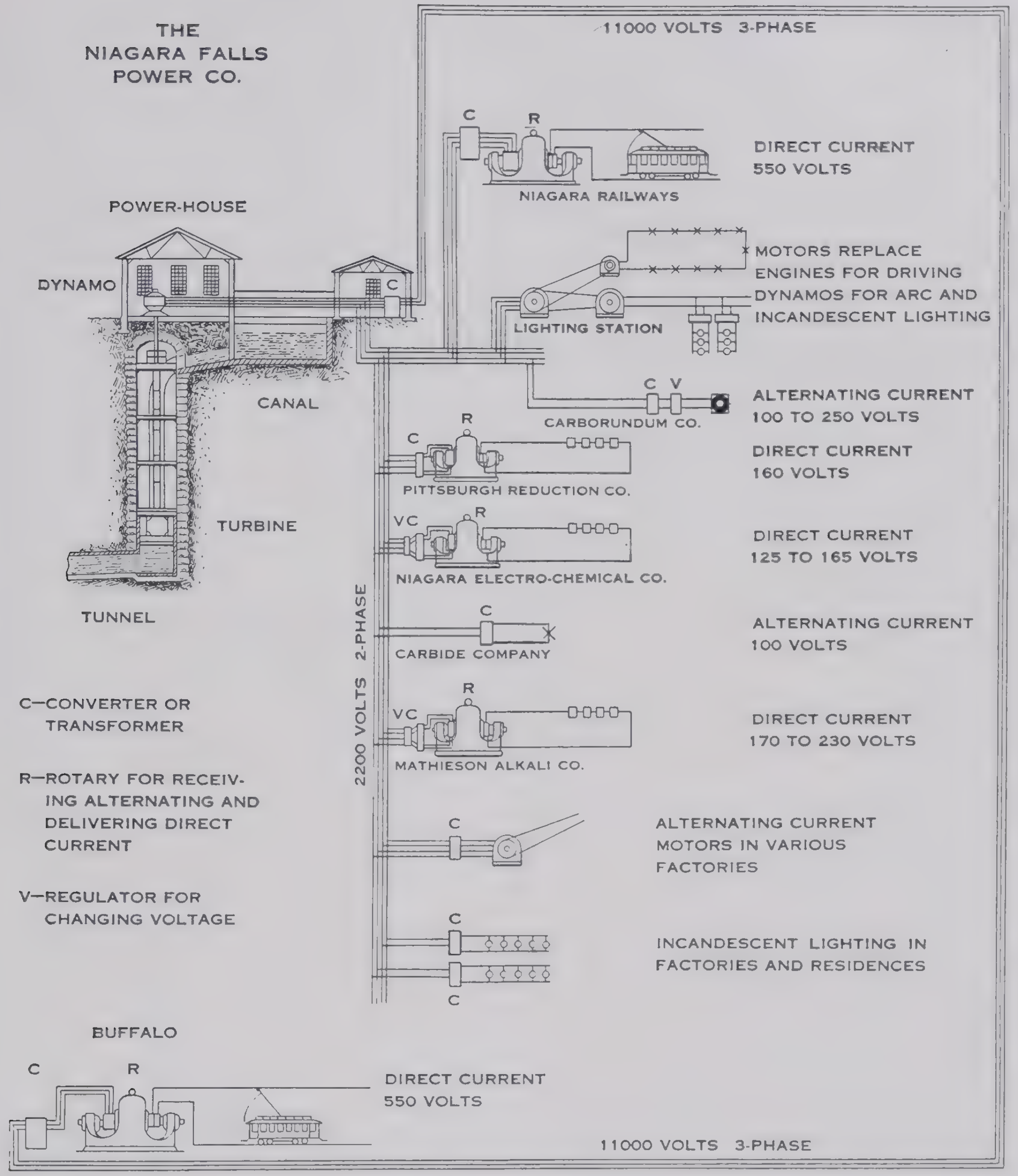
THE NIAGARA FALLS POWER CO.
11000 VOLTS 3-PHASE
C
R
DIRECT CURRENT 550 VOLTS
NIAGARA RAILWAYS
POWER-HOUSE
DYNAMO
C
MOTORS REPLACE ENGINES FOR DRIVING DYNAMOS FOR ARC AND INCANDESCENT LIGHTING
LIGHTING STATION
CANAL
C V
ALTERNATING CURRENT 100 TO 250 VOLTS
CARBORUNDUM CO.
R
C
DIRECT CURRENT 160 VOLTS
PITTSBURGH REDUCTION CO.
VC
R
TURBINE
DIRECT CURRENT 125 TO 165 VOLTS
NIAGARA ELECTRO-CHEMICAL CO.
TUNNEL
2200 VOLTS 2-PHASE
C
ALTERNATING CURRENT 100 VOLTS
CARBIDE COMPANY
C—CONVERTER OR TRANSFORMER
R
VC
DIRECT CURRENT 170 TO 230 VOLTS
MATHIESON ALKALI CO.
R—ROTARY FOR RECEIVING ALTERNATING AND DELIVERING DIRECT CURRENT
C
ALTERNATING CURRENT MOTORS IN VARIOUS FACTORIES
V—REGULATOR FOR CHANGING VOLTAGE
C
INCANDESCENT LIGHTING IN FACTORIES AND RESIDENCES
C
BUFFALO
C
R
DIRECT CURRENT 550 VOLTS
11000 VOLTS 3-PHASE

Diagram of Circuits

from a paper on "The Installation of The Niagara Falls Power Company," Engineers' Club of Philadelphia, April 17, 1897

RESULTS OF THE ADOPTION OF ALTERNATING CURRENT

CHAPTER XXIV

RESULTS OF THE ADOPTION OF ALTERNATING CURRENT

CHAPTER XXIV

THE ESTABLISHING OF CENTRAL STATION POWER

THE original Evershed plan, upon which the development of The Niagara Falls Power Company was based, contemplated the development of hydraulic power locally in each of two hundred or more wheel-pits of mills occupying a considerable district along the northern side of the river extending from 1 to 3 miles above the falls.

The story of the evolution from this plan to one involving a central power station from which power should be electrically distributed to local mills and factories and also to those at considerable distance has been recounted in other chapters. It has been repeatedly emphasized that there was no precedent for the distribution and transmission of power over extended areas on a large scale instead of producing it locally by engines or water-wheels. The central station for the supplying of electric light was less than ten years old and the central station plan had been visioned only by a few as a method for the general distribution of power, and those who entertained such hopes did not find in the electrical apparatus and methods then in existence the means of large scale dependable power service.

The industrial revolution of the nineteenth century had been brought about by the steam engine. The progress in material development and of the new civilization which it made possible came from the driving shaft of the steam engine and here and there of its companion water-wheel. The Niagara power proposition of 1890 was the largest which had been undertaken there or elsewhere and the proposal to introduce, in a development of 200,000 horse-power or more, a new method of central development and distribution of power was a radical and revolutionary proposal.

What has been the outcome? The early plan of supplying certain customers with water for their use in the operation of their own wheels was realized in but a single case in the International Paper Company, located near the power-house, which discharged the water from its own wheels into the main tunnel. All other power was generated in Power-houses Number One and Number Two, and then distributed as electric power to other plants for use. This practise, successfully inaugurated at Niagara, is now universal and commonplace. The central station method of developing power inaugurated a new era in the production and use of power, and in the contribution it makes to the progress of civilization.

ALTERNATING-CURRENT SERVICE FROM THE NIAGARA PLANT

In the light of subsequent history, it is now difficult to realize the point of view of the early advocates of direct current.

The use of current of this type is now restricted to a few fields where the character of the current is dictated by the use which is to be made of it. In certain electrochemical processes, direct current is essential; where storage batteries are used, it is requisite; for the operation of street cars it is desirable; in certain isolated plants and in industries where motors require a particular range of speed control it is preferable. But aside from such cases, it is used but little today, except that the early direct-current lighting systems in the centers of a number of our larger cities are still in operation. In practically all of these cases, however, the power is initially produced in large central stations as alternating current and is transmitted as such to a number of substations where it is converted into direct current in amounts as required for local use. In general, the direct-current distribution in cities is not being extended, but is being replaced by the alternating service, and in most cases, it has disappeared entirely.

The direct current did not lend itself to the operation of what may be termed a universal system. In the early projects for use of direct current at Niagara several types of generators were proposed, some for low voltage distribution locally, some for higher voltage distribution locally, and some for transmission to Buffalo. Generators of the several groups were not interchangeable.

Direct-current generators, owing to their inherent construction with commutator and brushes, have not been found practicable for construction in larger sizes. Very few such generators exceed 3000 or 4000 horse-power in capacity and in large sizes they are not capable of being operated at high speed. It is interesting to note that the choice of turbines for 5000 horse-power at Niagara seemed to eliminate the consideration of direct-current generators which were necessarily of smaller size.

Lord Kelvin, having in view the operation of a number of direct-current machines from the vertical turbine shaft by means of specially devised gearing, cabled on May 1, 1893, as follows:

> Buffalo project realizable immediately; have designed special easy gearing twenty or similar number continuous current dynamos, vertical shafts above ground around main turbine shaft; its design unchanged from present plan; delay till autumn unnecessary; trust you avoid gigantic mistake of adoption alternate current.

On the other hand, the alternator has been built of increasing capacity producing at Niagara more than 70,000 horse-power in continuous operation.

The speed of alternators is in general limited by that of the prime mover rather than by the alternator itself.

Direct current when applied to long-distance transmission at high voltage employed the constant current method instead of the constant voltage and this plan is not well adapted for supplying motors in different places, but simply for the operation of motors in one receiving station. Although as an electrical method for performing this service it has certain advantages, yet it has been realized in but few installations, none of importance.

The outcome of the choice of alternating current has been that it has served for the supplying of electric power for all purposes locally at Niagara as well as for transmission to Buffalo and other and more distant places, and that the Niagara method is in practically universal use.

NIAGARA POWER FOSTERS INDUSTRIES

One of the far-reaching results of the adoption of alternating current is the present character of the service it renders. The first idea at Niagara was the delivery of mechanical power from many wheels to local mills. Later, in 1890, invitations for projects to be considered by the International Niagara Commission described the purpose as the supplying of some electrical service and of power for manufacturing both at Niagara and at Buffalo.

In the first request by The Cataract Construction Company for proposals in the latter part of 1891 the service specified was for municipal lighting and for motors of local factories within a radius of two miles up to 300 horse-power. On February 15, 1893, which was six months or more before the contract for generators was placed, it was stated by the company that the inquiries and requests for power justified the belief that "a quick and urgent demand for this power, both hydraulic and electrical, will show itself at Niagara as well as at Buffalo, but undoubtedly it is from this great city now employing more than 50,000 horse-power that the more urgent demand will come for immediate use." The demand for hydraulic power never materialized beyond the single customer, i. e., the International Paper Company which after a time found the direct use of water for the development of its own hydraulic power to be so inefficient that arrangements were made for shutting down its independent hydraulic plant and operating the paper mill by electric power from the main power-house of the Niagara power company.

Furthermore, the more urgent demand for immediate use did not come from Buffalo, as is indicated by the report to the stockholders December 15, 1896,[1] fifteen months after the beginning of commercial operation. At that time, the power supplied and the contracts already made called for slightly over 15,000 horse-power although there were but three 5000 horse-power units then in operation. Buffalo had been receiving only 1000 horse-power. It was recommended that provision be made for increasing the capacity to 35,000 horse-power and for augmenting the Buffalo line so that it would be sufficient to deliver 10,000 horse-power as required by the municipal franchise.

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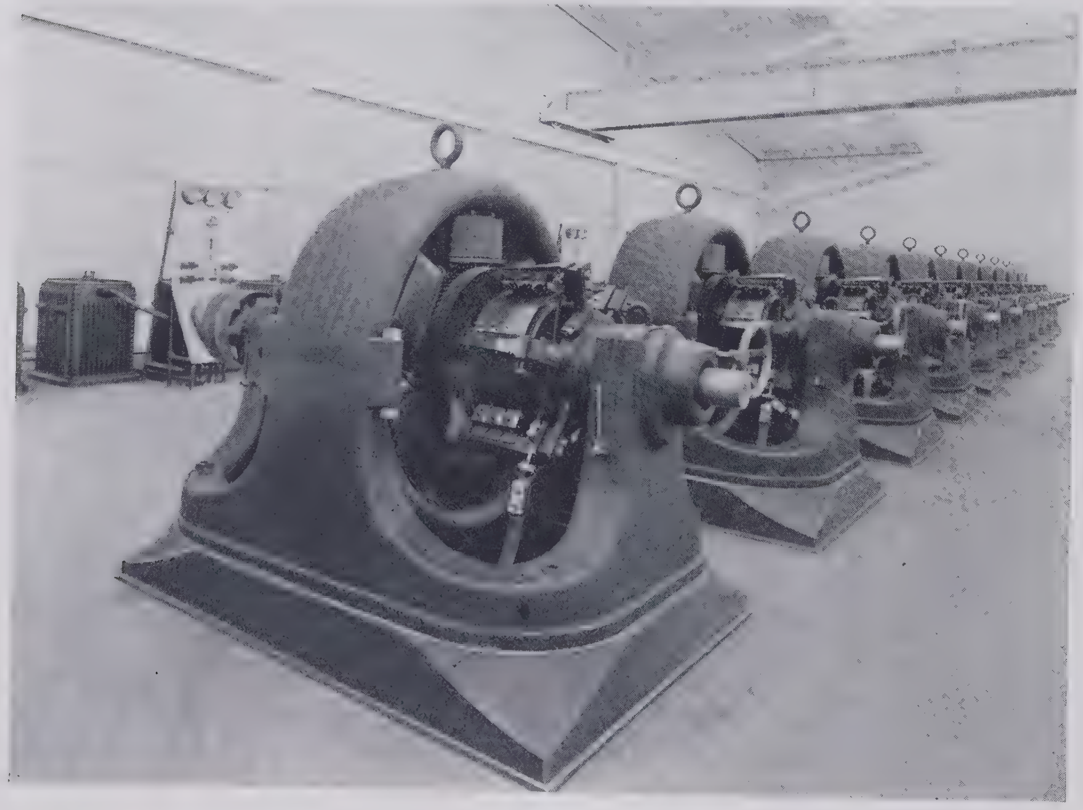
[1] See Chapter XXIII, pages 246–247, Volume II.



Rotary Converters, Mathieson Alkali Works, with Transformers and Voltage Regulators, 126 Kilowatts, 170 to 230 Volts

Buffalo was not, therefore, the field of "quick and urgent demand" but the large consumption of electrical power was then local and from unexpected and novel sources.

Furthermore, a glance at the diagram of circuits[1] showing the use of Niagara power in 1897, less than two years after the plant started, brings out a striking fact. Electric power was used for lighting, it was used for street railways locally and in Buffalo, it was used for motors in mills, the three uses of power which had been emphasized, but the center of the diagram shows five uses other than for lighting and power, of a kind to which scarcely any reference is found in the early prospectuses and plans of the company. These uses are for the making of carborundum, aluminum (Pittsburgh Reduction Company), alkalis and calcium carbide. They are electrochemical and allied processes and they were using, in the aggregate, many times the total power taken for lighting and motors. The load was not only greater but it was practically a continuous and constant load, 24 hours a day, whereas the railways called for an intermittent load for 16 or 18 hours. Many of the industrial motors were operating 8 hours and the lighting service was during the evening hours only. The adoption of electricity made possible these new uses of the wasting power of Niagara's waters and the adoption of alternating current had enabled these various kinds of service to be supplied from a single system and source. The low cost of continuous power had made profitable the inauguration of important industries of a new kind.

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[1] See Chapter XXIII, page 251, Volume II.

It is interesting to note that practically all of the various electrochemical processes then introduced had been invented, developed and made commercial after the taking out of the charter in 1886, under which the power-plant was organized. A new and practically unanticipated electrochemical industry had been fostered and immediately established, supplying new and useful products, as a contribution of natural resources and scientific achievement to the general welfare.

OTHER POWER-PLANTS AT NIAGARA

The development of other electric power-plants at Niagara immediately after the successful inauguration of service by The Niagara Falls Power Company is significant. That a power-plant of 200,000 horse-power seemed large may be inferred from the expectation that the quick and urgent demand for power would come from Buffalo because some 50,000 horse-power was employed there, while little was in use at Niagara. The local demand for power had in the past been met by the use of a few thousand horse-power from the "hydraulic canal" although it had been in service for many years. The hydraulic company had furnished a small amount of current for arc lighting and for incandescent lighting and for other purposes by various dynamos and circuits each adapted to the customers' needs, but it now inaugurated a power system on a comprehensive scale by the adoption of the alternating-current system similar to that of The Niagara Falls Power Company. Soon there were larger enterprises on the Canadian side of the river for power development, all of which adopted the alternating-current polyphase system corresponding to that of The Niagara Falls Power Company so that all generators were adapted for interchange of power or for supplying a common system.

One result of the adoption of alternating current was to give a new order of usefulness to the "hydraulic canal" and also to stimulate new enterprises for the utilization of the waters of Niagara, for the benefit of the people on both sides of the international boundary line.

Niagara power, now produced in several power-houses on each side of the river, divided by an international boundary line, constitutes physically a single family or city of interconnected power-plants under different ownerships and control. This group forms the greatest hydro-electric development in the world. To the north and the south two great areas of people are served with light and heat and power over radiating transmission lines, while the local electrotechnical factories send forth products which are essential to industries everywhere. And the method by which all this is done is that inaugurated by The Niagara Falls Power Company when it began operation in 1895.

INFLUENCE OF NIAGARA ON POWER DEVELOPMENT ELSEWHERE

The adoption of the central station method of producing and distributing power, the inauguration of generators some five or ten times former capacities, the adoption, in the largest electrical enterprise ever undertaken, of the alternating-current polyphase system which had been so much criticized and discussed, the immediate success in operation—all gave an impetus and confidence in electric power development which was followed by enterprises on a large scale elsewhere. In New York City, for example, within a few years, a number of large power-plants were constructed for supplying the lighting systems, the street railways, the elevated railways and the subways, and all adopted the alternating-current polyphase system employing 25 cycles following the precedent set by The Niagara Falls Power Company. During the decade following the starting of the Niagara plant in 1895 the capacity of the electric power stations of the country quadrupled, and polyphase alternating current had become the practically universal method of generating and transmitting power, at 25 or at 60 cycles.

Niagara was the mecca of engineers from abroad. At the time of the World's Fair in 1893, when the hydraulic construction was well under way, there were many engineers and others of distinction visiting this country from abroad who went to Niagara to inspect the work and to learn of the plans in view. After the beginning of commercial operations there continued a succession of foreign visitors who carried back to their homes the practise and the inspiration which this great plant afforded.

In 1890, at the beginning of the project, it was clearly shown that in the most important departments there were no precedents to follow and that the special problems at Niagara were to be worked out practically and commercially only by the aid of the most advanced developments of several branches of applied science operating in close union or alliance.

This enterprise, as it exists today in successful operation, represents the union of geology, physics and other sciences with civil, mining, hydraulic, mechanical and electrical engineering, which, each in its turn, have contributed to the foundation of hydro-electric power as a mighty influence in the promotion of industrial arts based upon mechanical, chemical and metallurgical sciences.

Interior View of Electrical Conduits in Main Subway

INTERCONNECTION OF POWER SYSTEMS

The outstanding advance in recent electrical power methods is the interconnection of generating stations by transmission lines, thus forming extended networks of transmission lines.

This is another step in the progressive growth in the scale of electrical operation which has followed the engineering developments which have made successive steps.

In the early days of electrical service, local plants supplied limited areas and different kinds of current were required for incandescent lighting, for arc lighting and for electric railways. Alternating current was at first a means of extending the radius of incandescent lighting from about a half mile from the direct-current central station to several miles from the alternating-current station. Larger cities required ten or a dozen electric plants for serving their different districts.

Then came the polyphase alternating current, by which all kinds of service could be supplied from a single large central station, a method first exploited on a large scale at Niagara. A single large power station is far cheaper to install than many small ones; it can be located where favoring conditions direct and not where proximity to the load compels; it is more efficient and economical to operate and the aggregate capacity required is less than is necessary when several smaller stations separately supply their varying loads.

Increases in voltage have enabled a station to serve larger and larger areas, and have made it possible for a distant water-power to serve a city. As voltages became higher, insulators for supporting the line were made larger until a mechanical limit in size was reached. As a consequence a voltage limit was also reached at about 66,000 volts. The insulator problem was solved at Niagara by the development of the suspension type insulator, which has made it practicable to use voltages of 220,000 and more.

The next great step has been the interconnection of power systems into what is often termed the super-power system. The power stations of different districts are forming great networks of transmission lines or "pools of power" supplied by many power stations. No longer is each district dependent upon its own local source of power, but when demand is great or emergency arises it can draw from distant sources. Water power-plants with varying flow, far exceeding the local demands at certain seasons, can supply all their energy to a large system and when the demand for power exceeds that which the hydraulic plant can supply the supplementary power can be furnished by a steam station. Thus, power can be supplied from those stations where it can be most economically produced, water-power is conserved, coal is saved, power station capacity and investment are reduced, continuity of supply is assured.

In a few decades there has been a great transition from the old method of individual engines or water-wheels driving their loads by shafts and belts to the universal electric power system, hundreds of miles in extent and rapidly becoming nation wide. And the electrical method by which all this is being done is that which, after years of investigation, was adopted by The Niagara

Falls Power Company in its great pioneer enterprise. No other means is known by which this could be accomplished. Hydraulic methods and compressed air, urged in the beginning, now seem ludicrous and the use of direct current is confined to a few restricted fields. The choice of polyphase alternating current has stood the test of time, for the tens of millions of horse-power produced electrically in great steam and hydro-plants which are linked together by transmission networks are generated as alternating current. The Niagara power system, thirty years ago without precedent, now appears as a miniature of the electric power service which is making electricity the greatest tool that ever came under the control of man.

AMERICAN MANUFACTURING COMPANIES

The Niagara project, as is elsewhere indicated in the pages referring particularly to the large electric manufacturing companies in America, was a great stimulus for the building up of their organizations and the development of a new system preparatory to the competition for the initial contracts at Niagara. The continuing contracts from the company itself and from its customers and the stability and confidence which the enterprise gave to electrical power development in general, are matters for which these companies have been appreciative.

As careful students of the methods of power transmission at home and abroad in 1890; as eager investigators of conditions at that period in the arts of engineering; with intimate knowledge of the promptness with which the two great electrical manufacturing companies recognized the radical economic changes that were taking place and prepared to grasp the opportunities presented, the survivors of the Niagara enterprise of 1890 congratulate the leaders of those two national organizations upon their vision, their masterly organization, and their successful achievement of reputation and fortune in their campaign at Niagara.

In recent years, representatives of the General Electric and the Westinghouse companies in a retrospective view of a period of more than thirty years have expressed the following sentiments:

General Electric Company

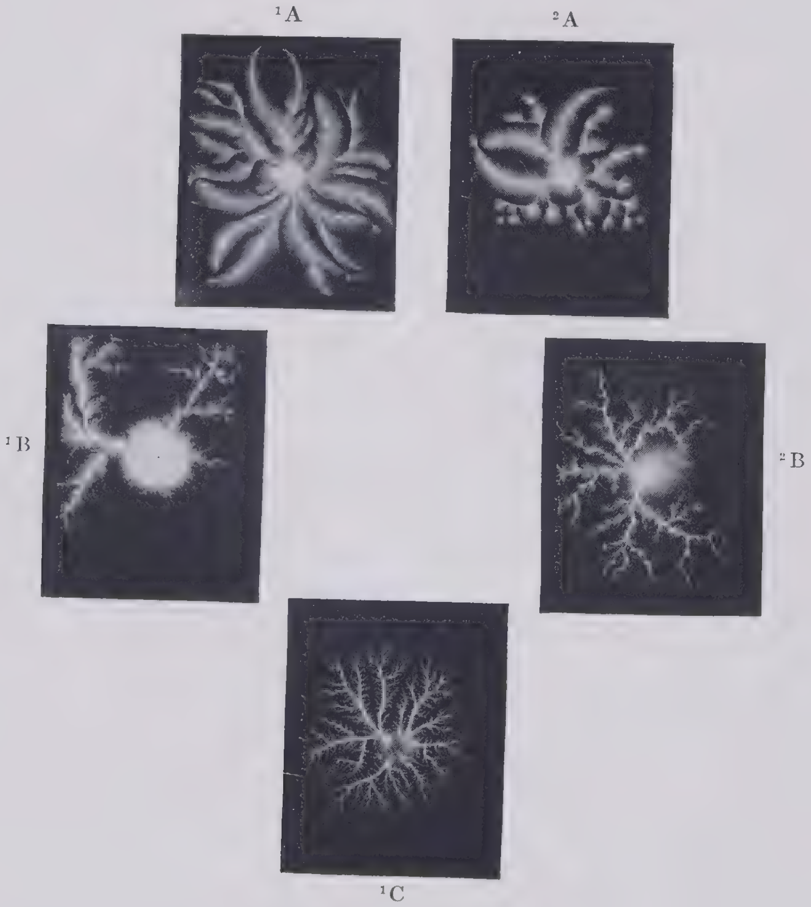
> The original installation at Niagara Falls had a profoundly important effect upon the development of the electrical art, and the decisions originally made and the reasons which governed them have an importance entirely apart from that which governed later developments.
>
> William LeRoy Emmet
> Consulting Engineer

Westinghouse Electric and Manufacturing Company

The abundant and widely distributed supply of electricity will confer innumerable benefits upon the people of the United States. It will increase the productivity of farms, improve transportation, reduce the cost of manufactured products, increase the effectiveness of human labor, conserve our diminishing fuel resources, and, by providing ample facilities for industry and for comfortable living in smaller centers, it will draw people out of the congested cities. In a word, it will decentralize and so enhance our welfare that it will usher in a new era in the country's history.

It is significant that in the evolution of the new electric power, the great step should have been made at Niagara. Here hydro-electric power sprang into being, a young giant. The spiritual influence of the beauty and majesty of Niagara are now supplemented by a beneficial service to all within the wide reach of its radiating circuits and by its example to people everywhere.

Guy E. Tripp
Chairman of the Board



^{1}A, ^{2}A Negative Electric Discharges from Induction Coil.
^{1}B, ^{2}B Positive Electric Discharges from Induction Coil.
^{1}C Oscillatory Discharge from Leyden Jar.

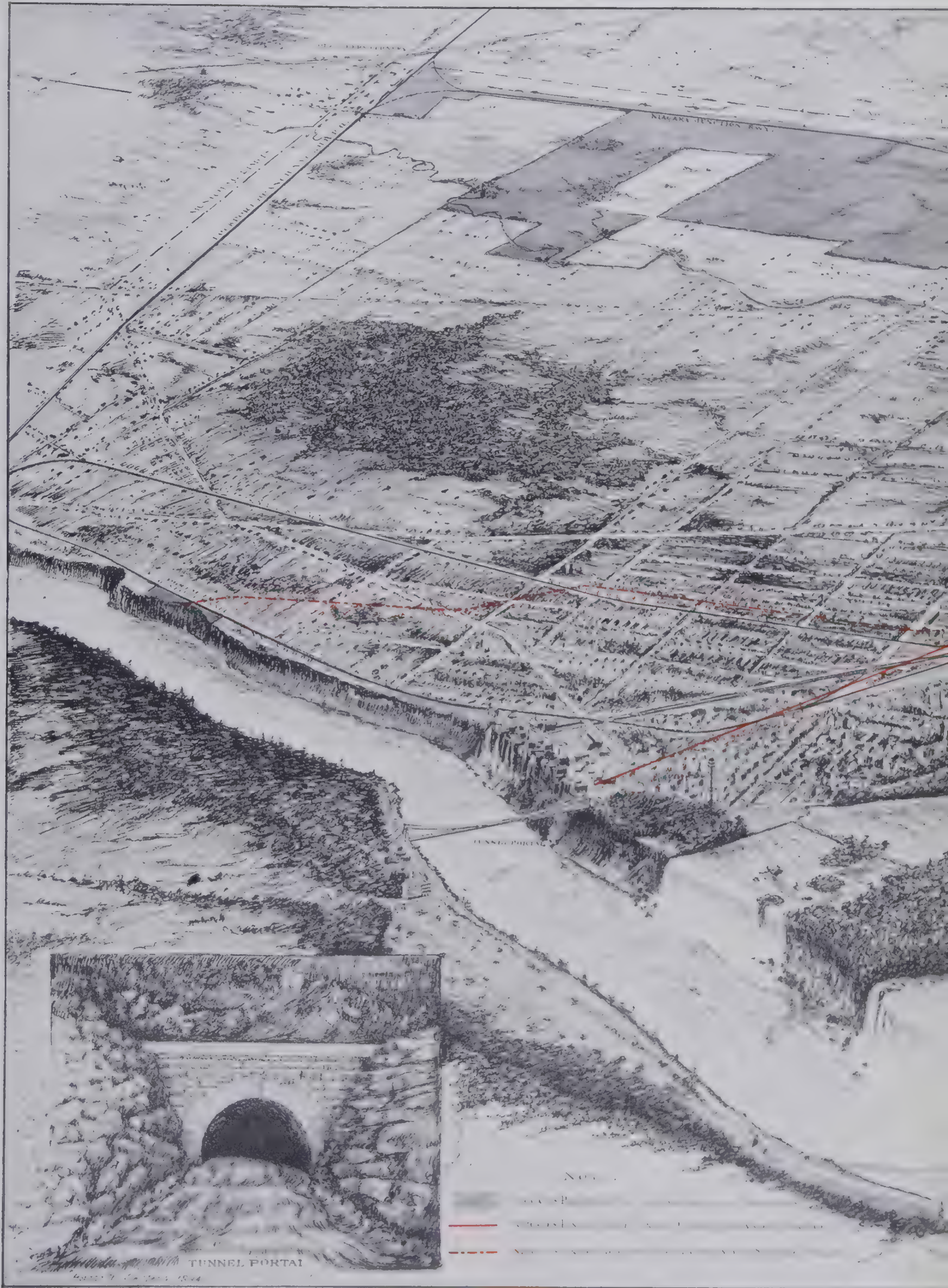
BUFFALO TRANSMISSION

CATARACT POWER AND CONDUIT COMPANY, 1896

AND

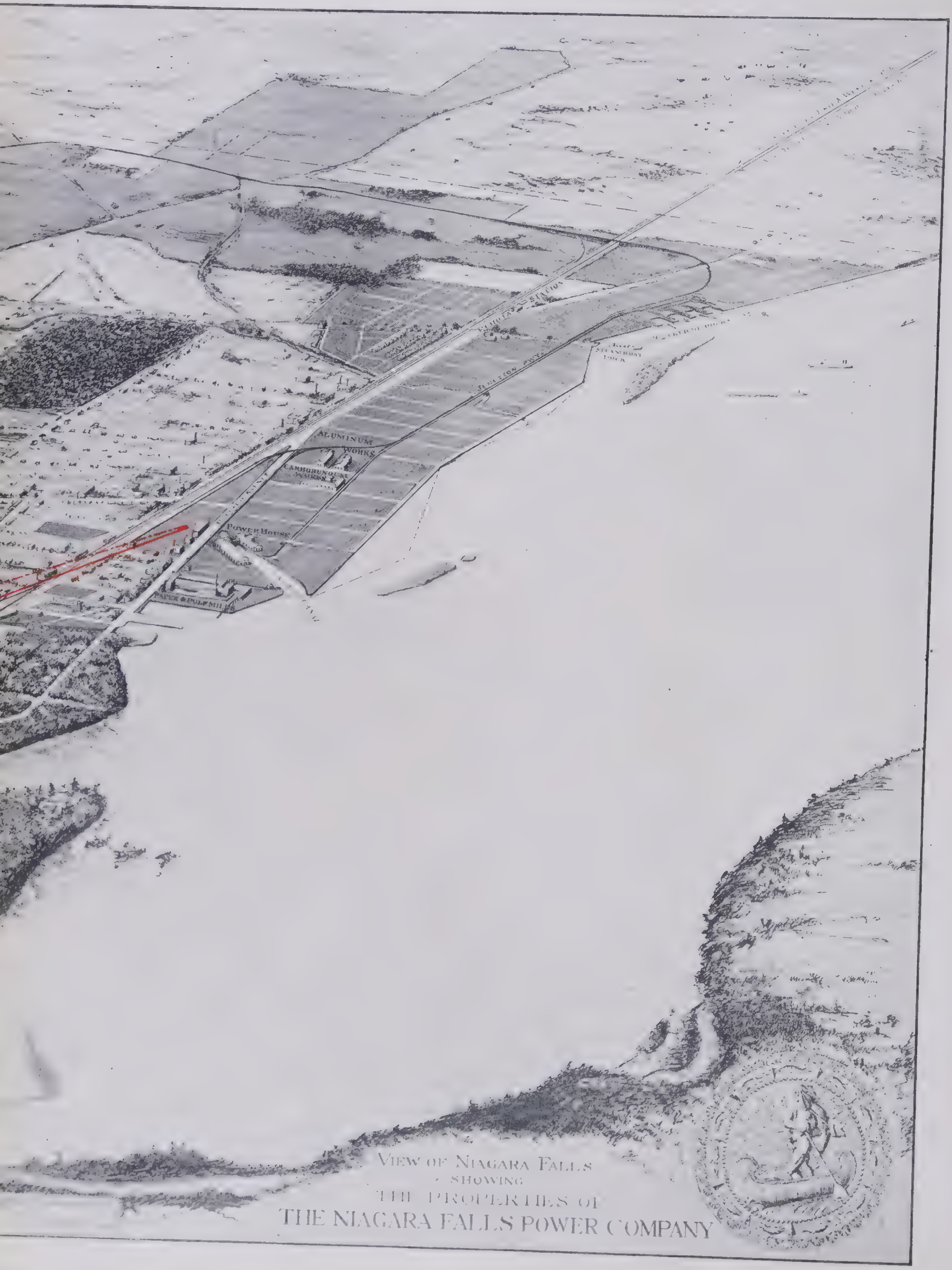
BUFFALO, NIAGARA AND EASTERN POWER CORPORATION, 1925

CHAPTER XXV



VIEW OF NIAGARA FALLS SHOWING THE PR

From a Drawing b



s of The Niagara Falls Power Company
e Wells Sellers, 1894

BUFFALO TRANSMISSION

CATARACT POWER AND CONDUIT COMPANY, 1896

AND

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CHAPTER XXV

TRANSMISSION VITAL TO THE NIAGARA PROJECT

THE transmission of power, and on a scale unprecedented, was at the outset of the Niagara project considered essential to its commercial success. There seemed no prospect of quickly attracting to Niagara industries which would prove large users of power, while Buffalo and beyond was an alluring goal. Not in all the world was power aggregating the output of a single unit proposed at Niagara transmitted a quarter the distance from Niagara to Buffalo. The quest for a method to transmit power was the greatest task of the International Niagara Commission. But no method deserving a major award was forthcoming. Pneumatic and electric methods were advocated with about equal emphasis. When the initial plans were made for two power-houses, one on each side of the inlet-canal, one was designated as electric and the other as pneumatic.

ELECTRICITY VERSUS COMPRESSED AIR

One of the facts in the early Niagara power history which is most surprising to the readers of today is the recommendation of George Westinghouse in 1890 that compressed air should be used as a method for conveying power to local factories and to Buffalo. He has been recognized in this country as a pioneer and leader in the development and use of alternating current for lighting and for long-distance transmission of electrical power. This surprise is indication that today it is almost impossible to realize the situation at the earlier date. Today electric transmission is so commonplace that it is taken for granted. The simple fact is that electricity was not capable of handling a large undertaking at that time. Nor did the Niagara company's officers and engineers find in Europe any installations of compressed air power transmission or of hydraulic transmission which gave them assurance that these methods would serve their purposes but, trusting to rapid progress in electrical development, and with provision for compressed air distribution from one power-house as well as electrical transmission from the other, they had the courage to proceed.

The outcome has been that electrical power distribution is well-nigh universal and that compressed air is used only in limited and special cases notably where reciprocating machinery such as drills can be advantageously operated by this means.

INITIAL STEPS IN ELECTRICAL TRANSMISSION

When the electrical system was finally determined by the placing of contracts for polyphase alternating-current generators in 1893, the way was clear for taking up the specific problems of electrical transmission.

Prof. E. J. Houston and Dr. A. E. Kennelly, of Philadelphia, were consulted in 1894–1895 as to the radius of electric power distribution that might be reasonably considered commercially profitable by the use of high-tension alternating current. As the result of their study of the principal elements they reported that in their opinion Niagara power could be delivered not only within the immediately surrounding territory, but that it was reasonable to anticipate that Niagara power might successfully in the future compete with that produced by local steam engines within a radius of 200 miles.

PROPOSALS FOR TRANSMISSION LINE

The engineers of The Cataract Construction Company prepared a definite project, and proposals for its construction were invited in the spring of 1894, coincident with the application to the city of Buffalo for a franchise for the distribution of power within that municipality. Proposals were received from the General Electric and Westinghouse companies which were in all essential respects alike. Each company proposed a project for the transmission of 10,000 horse-power from the bus-bars of the Niagara power-house to the substation at Buffalo, transforming the two-phase currents generated at the power-house into three-phase currents at either 11,000 or 22,000 volts by step-up transformers.

The General Electric Company designed a single pole line, with two circuits, and suggested, if desired, a second pole line with a spare circuit. The Westinghouse Company proposed to use two lines of steel poles, each to carry one circuit. The General Electric Company proposed to use air-blast transformers, while the Westinghouse Company advocated oil-insulated, water-cooled transformers. Active measures looking to the construction of the line were not undertaken until the latter half of June, 1896, owing to the delay in obtaining the Buffalo franchise.

The technical advisers of the construction company as to the system of transmission and the details of its design and construction were:

Prof. George Forbes, electrician, of London
Houston & Kennelly, electricians, of Philadelphia

Dr. Coleman Sellers, chief engineer, of the Niagara and cataract companies

DeCourcy May, mechanical engineer, General Superintendent of Works.

J. G. White
A.S.C.E., A.I.E.E., I.E.E.
Engineer

ERECTION OF TRANSMISSION LINE

The contractor for the erection of the transmission line was the engineering organization of J. G. White, then entitled The White-Crosby Company of New York.

Mr. White presented a paper entitled *The Niagara-Buffalo Transmission Line* to the National Electric Light Association at its meeting in Niagara Falls in 1897, after the line had been in service for half a year. The following extracts throw light on some of the difficulties which were encountered on this pioneer line:

My first personal knowledge as to the then proposed transmission line between Niagara Falls and Buffalo, dates from the autumn of 1894, when The White-Crosby Company was asked to prepare and submit detailed plans, specifications and proposals for its construction. It was then found that the engineers of the Westinghouse and General Electric companies had both recommended the construction of circuits of three wires, adapted to the three-phase system, each wire having an area of about 330,000 circular mils. Beyond this no definite plans had then been determined upon. The engineers of The Cataract Construction Company at that time considered it advisable to have the line built entirely of iron poles and detailed drawings and specifications were accordingly prepared and submitted, showing alternative plans. The first included two entirely independent lines of iron poles, not less than 40 feet long, weighing something over 2000 pounds each. The second consisted of lines of poles of about the same height, weighing 1000 pounds each, set in pairs and tied together by deep trusses, which served both as braces against the terrific wind storms that sometimes sweep across Lake Erie, and as a means of carrying part of the wires.

Repair Wagon and First Buffalo Transmission Line

Full proposals, with detailed plans and specifications for the construction above outlined, were submitted October 11, 1894, and the amended proposition for carrying out the construction on the same general lines was submitted March 13, 1895. Nothing further developed in the matter until June, 1896, when new proposals were asked for the construction of the line, on the assumption that white cedar instead of iron poles should be used throughout. Such proposal was submitted June 18th, and was accepted some days later.

First cost, within reasonable limits, should always be considered secondary to good construction, so that you will probably concur in awarding first place, as a factor in problems of this nature, to the avoiding of interruptions. . . Entering into this problem of sure and continuous operation, we have the same two factors entering that usually confront us in connection with any electrical installation; namely, insulation and mechanical strength. . . Of what importance to a 5000 horse-power dynamo is the current that would leak down a wooden pole, even when wet? Nevertheless, this same current is sufficient to char or burn the pin under a defective insulator. During one night last fall, while an attempt was being made to operate the line on temporary insulators—the best obtainable at the time—the ends of no less than five of the large cross arms used on this line were burned entirely off, and this, too, without any manifestation having been made at the station that anything unusual had occurred. This naturally raises the questions whether

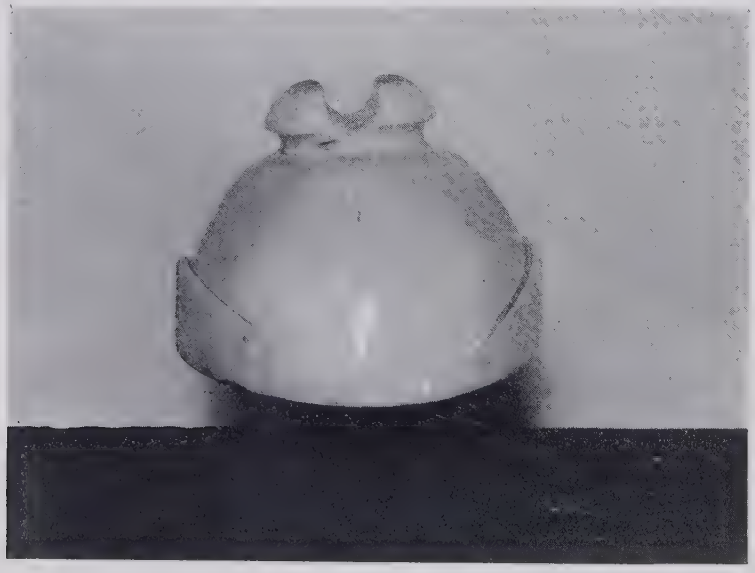
Raising Steel Pole for New Line to Replace Original Niagara-Buffalo Wood Pole Line it is possible to procure insulators that can be depended upon to maintain the insulation on a circuit carrying 10,000 volts or over, and whether it is not good practise to have fewer poles, and, consequently, fewer weak spots in the form of insulators.[1] . .

With spans of 100 feet, the pole would therefore have a factor of safety of only about 2½ when new, while the wires would have a factor of safety of about 7 and the cross-arms of about 26.[2] . .

INSULATORS

It is evident from the above that the weakest point of this line, mechanically, is the pole, in spite of the fact that final decision was made in favor of spacing the poles 75 feet apart on straight, and proportionally closer on curved, parts of the route. . .

This naturally brings us back to the question, "Are insulators such insurmountably weak links in such a chain, and is it not possible to get insulators that can be depended upon even when supporting wires under a pressure of 10,000 volts?" This can be most satisfactorily answered by again narrating the experience with this line. During the past eight months, insulators have been sent to Niagara Falls by four of the works which are among the first six in this country in the production of porcelain for electrical use. Of a sample lot of ten received a few days ago for test from one of these factories, one had broken in transit, eight broke under the strain of electrical pressure varying from 16,000 to 36,000 volts, and the last broke under 40,000-volt strain. This latter would seem to be a minimum safe test limit for any insulator expected to sustain a regular



Helmet Type Insulators

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[1] About ten years later this problem of designing a suitable insulator for use on a line with few insulators and long spans was solved as the result of investigations by H. W. Buck, electrical engineer of The Niagara Falls Power Company, by the invention of the suspension insulator now exclusively used for high tension transmission lines.

[2] Wires supporting structures are assumed to have a covering of ice half an inch thick.

strain of 10,000 volts and is a test that any mechanically good, well-vitrified insulator of ordinary design will pass. . . It is only fair to state that these insulators were of a smaller type than, and different design from, those in use in the Niagara line. Several lots of somewhat similar insulators from another factory gave about the same results.

Several thousand insulators, of a diameter almost equal to the round type now on the line, but of a design somewhat different in details, were furnished by a third porcelain works. These were all supposed to have been tested, and to have successfully withstood a pressure of 40,000 volts at the factory before shipment. When, however, these were tested at Niagara Falls by Mr. Lincoln, the electrical superintendent of The Cataract Construction Company, it was found that a large majority of them broke down under a 40,000-volt test, illustrating that a dry test, such as had previously been made, is useless for practical purposes. The method of test used at Niagara Falls was the "wet test."

As it was important that the line should be ready to deliver current by a specified date, the test was reduced on these insulators to 20,000 volts, and all that withstood this pressure were passed for temporary use. These insulators were later replaced by some of those now on the line, all of which successfully passed a 40,000-volt test made as above described. The temporary insulators after removal from the line were tested under 40,000-volt pressure; a solitary insulator, from a total of 1150 was able to pass muster.

Of the insulators shipped by the fourth factory, and of the two types now on the line, about 24 to 40 per cent were usually found to be defective, breaking down under 40,000 volts; this percentage decreasing in the last shipments received. It is, however, worthy of special note that since the last of the temporary insulators were removed from the line, there has not been one minute's suspension of current supply due to defective insulators. . . Apparently, therefore, it has been demonstrated that it is possible to secure insulators that are reliable. That there have been no greater troubles in the past from defective insulators is probably due to the fact that most of the large transmission plants in operation under high voltage, up to within a few months, have been in the far West, where a climate prevails very different from that natural to this immediate region.

EARLY OPERATION OF BUFFALO LINE

Before closing, it is natural to ask, "Is the line as built a genuine success? Can it be depended on, and is it effective?" In answering, let me give briefly some of the facts. The line now in operation is over 26 miles long, of which the last 4000 feet is under ground, the current being carried in lead-covered cables with rubber insulation, these having been drawn into terra cotta duct conduit built especially as a part of this line. These cables successfully withstood a test of 40,000 volts, are guaranteed for five years under working pressure up to 25,000 volts, and were punctured during test only by a pressure estimated by Mr. Lincoln as about 80,000 volts. They have given no trouble since the current was first turned on the line, November 15th last, except at two imperfectly made joints. Except for the short time needed to repair one of these joints, there has not been a single shut-down chargeable to the transmission line itself since the last temporary insulators were removed, some three or four months ago. A number of interruptions to service have occurred during that time, due to derricks used on the work now being done on the Erie Canal hitting wires, undermining the poles and

> conduit by this work, and to allow new lightning arresters to be put in circuit at transformer houses. Except for these extraneous and unusual causes, the service has been perfect, with the slight exception noted above. One short interruption last winter was due to the dead limb of a tree blowing across the wires, illustrating the fact that all trees should be cut down for some considerable distance on both sides of any high-voltage line. . .
>
> The actual working efficiency, as shown by the wattmeters in the low-tension alternating circuits at Niagara, and the direct-current 500-volt circuit at Buffalo, was 79.6 per cent, this being for a considerable period and a fluctuating load. This efficiency included loss in step-up transformers, line, step-down and rotary transformers. . . In view of these figures, we hope you will feel warranted in indorsing the opinion that Niagara power is now being satisfactorily delivered in Buffalo. . .
>
> As a final deduction, it seems reasonably certain that it is now possible to build either overhead or underground transmission lines—even in regions subject to much cold, damp weather—capable of carrying current at 10,000 volts, or higher, pressure, which can be operated with efficiency and every assurance of uninterrupted service.

In the discussion of Mr. White's paper, insulators, lightning protection, the relative cost and desirability of overhead wires and underground cables were the topics which developed special interest. In the light of subsequent development two points of view are notable. A gentleman who is now at the head of one of the largest transmission systems of the country began his discussion with this sentence, "When I first saw this overhead line, what seemed to impress me particularly was the awful responsibility of running such high potential above ground." Another gentleman, the head of an important street railway, made this remark, which was endorsed by two other eminent electrical men, "I very seriously question whether even this great plant at Niagara Falls can compete with the modern steam plant 50 miles from Niagara Falls."

REPORT OF OPERATING SUPERINTENDENT

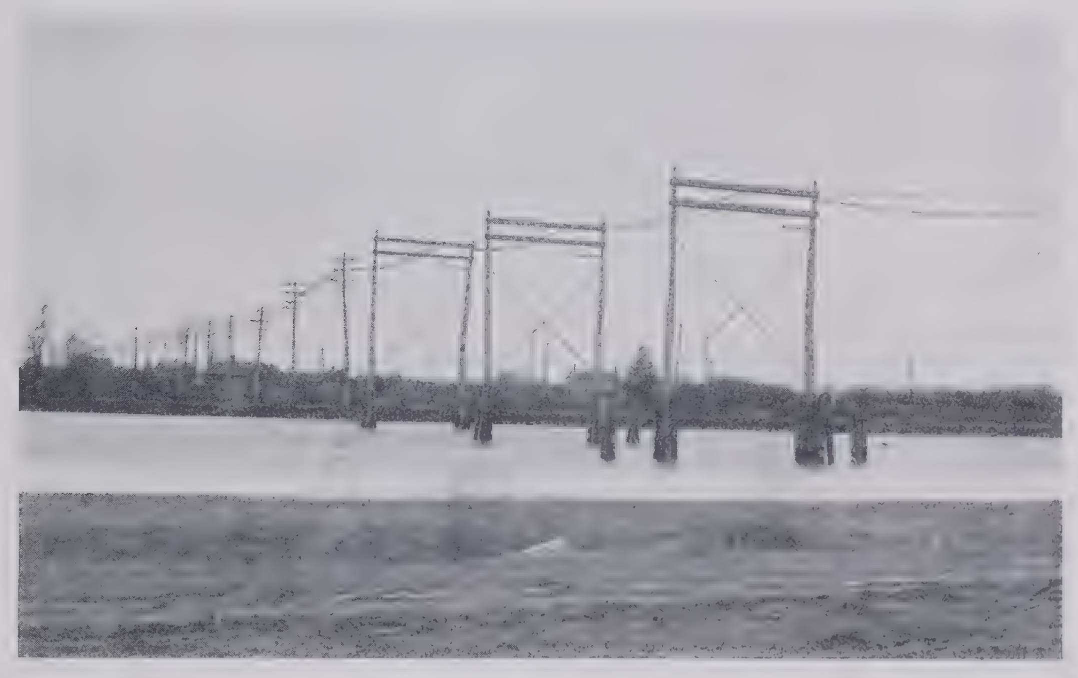
The supervision of the details of material and erection of the transmission line was the responsibility of the company's resident electrical engineer and operating superintendent, Paul M. Lincoln, who describes his work in this connection by the following statement made in 1920:

> The first Niagara-Buffalo transmission line on the American side of the Niagara River went into service during the fall of 1896. As the operating superintendent for The Niagara Falls Power Company, it became my duty to supervise the operations of this transmission line from the time it went into service in 1896 until I severed my connection with The Niagara Falls Power Company in May, 1902.
>
> The status of electrical transmission as of that date has been set forth in the preceding chapters. Suffice it to say that at that date the use of alternating currents for lighting was only ten years old and its use for power purposes was almost unknown.

The few previous attempts to use alternating currents for power purposes were exceedingly crude and were on a much smaller scale than that proposed for the Niagara-Buffalo transmission.

In the construction of the Niagara-Buffalo transmission line, such precedents as then existed were followed. These precedents in turn had followed the practise of telegraph construction—the only precedent there was to follow in that day.

The following statement is based on my personal recollections of six years direct contact with this transmission, and is reinforced by the opportunity which has been afforded me of perusing the correspondence that passed at the time when the purchase of equipment for this transmission was contemplated.



Original Pole-line Transmission to Buffalo

The construction of the Niagara-Buffalo line followed the recognized practise of the period for telegraph lines—the only precedent there was to follow at that time. The poles, cross arms, pins and insulators were of course heavier than those used in telegraph practise, also all poles on curves were either braced or guyed. At corners, double poles were used, but in other than these details construction was very similar to that used in the telegraph practise of the day.

The photographs reproduced herewith show but a single line on the poles; this is because these particular photographs were taken before the second line was erected. To meet the problem of continuity of service it was essential to have more than one transmission line available for use at all times. Two such lines were installed at the beginning, either one of which would easily carry all the power taken by Buffalo during the first few months or year. It was always the policy of The Niagara Falls Power Company to have a sufficient number of lines in service so that at any time one line could be shut down for inspection or repair and the remaining lines could easily carry all the power required.

The Niagara-Buffalo line was a relatively short one, only about 22 miles from the step-up station in Niagara to the step-down sub-station in Buffalo. Today this would hardly be called a transmission, but rather an enlargement of the distribution area. Also, the voltage used was not high—11,000 volts—3-phase—a voltage that today would be viewed as a distribution voltage. Other plants, even at that time, were transmitting power at higher voltage than that. However, in some aspects the Niagara-Buffalo transmission was unique and of historical importance. In the amount of power transmitted and in the importance of the service rendered by the transmitted power, the Niagara-Buffalo transmission transcended anything that had been attempted previously. The first load in Buffalo to be operated by this transmitted power was the street railways of Buffalo. Any failure of transmitted power was, therefore, heralded immediately throughout the entire community. Other loads were soon added which were almost as important. The first requisite for transmitted power was therefore *continuity.* It soon developed that the success or failure of Niagara power in Buffalo depended on keeping the supply *continuously* available in Buffalo. Then, therefore, began the long battle for *continuity of service*, a battle that has been waged not only on the Niagara-Buffalo line but on every other transmission line that has gone into service since then.

In 1896, transmission line equipment was not what it is today. Lightning arresters were totally inadequate; the oil switch was not yet known; the insulator was woefully defective, and such a thing as reversed power protection was not even dreamed of. The experiences of the Niagara-Buffalo transmission were to have a material effect on the evolution of transmission technique.

LIGHTNING

Lightning was one of the first as well as one of the most formidable enemies that the Niagara-Buffalo transmission had to fight. There never has been a complete answer to the lightning problem but at that period there was hardly even a beginning to the later progress. The bettering of line insulation and construction has been one of the chief factors that has reduced interruptions from lightning. Nothing has been developed that has eliminated *all* interruptions from lightning and in my opinion there will be no such development. A direct stroke of lightning is almost sure to cause an interruption of service on the line affected; if beyond this, equipment attached to the transmission line is not destroyed, the operators may consider themselves fortunate. Direct strokes, however, are not common and it is a lucky thing for the transmission of electric power that this is the case. But there are severe strains imposed on the insulation of transmission lines and the equipment connected thereto whenever lightning occurs anywhere in the neighborhood of a transmission line. The severity of these strains depends on the severity of the lightning discharge as well as its proximity. Against these indirect effects it is possible to secure some degree of protection. In 1896 the amount of protection that could be secured was an unknown quantity.

Alexander J. Wurts of the Westinghouse Company had been doing some valuable work on the problem of lightning protection.[1] He had developed a so-called "non-arcing" lightning arrester—a series of cylinders made up of metal that would permit the lightning discharges to pass but presumably would prevent the generator current from following. These arresters were tried out on the Niagara-Buffalo transmission line with considerable hope that they would perform as expected. However, it was soon found that the low frequency in use on the Niagara system coupled with the large amount of power in the installation back of the line, caused almost a complete failure of the so-called "non-arcing" properties of these arresters. An arrester which would operate with perfect success on a system of a few hundred kilowatts failed utterly to quench the arc when the Niagara generators were back of that arc. This was one of the points where the size of the Niagara system introduced a new problem. It was found that in order to make these arresters suppress the arc successfully it was necessary to introduce a resistance into the discharge circuit to limit the amount of current that could flow. This in turn limited the effectiveness of the arresters.

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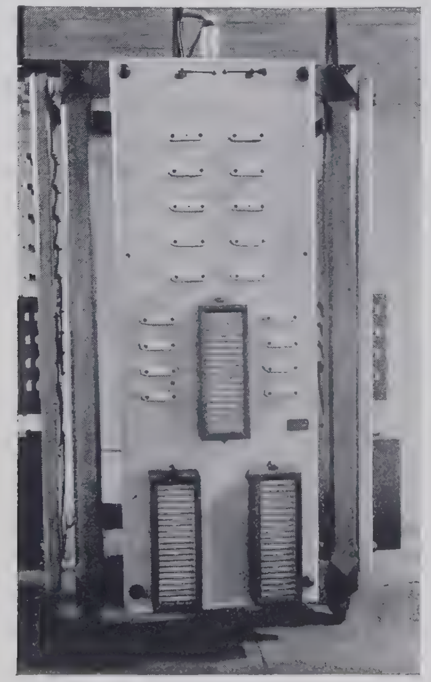
[1] See paper by Mr. Wurts, Trans. A.I.E.E. March, 1892 and May, 1894.



Wurts' Lightning Arrester at Niagara End of
Buffalo Transmission Circuit, 1913

Both the Westinghouse and the General Electric companies worked ardently on this lightning arrester problem but neither was able to produce a complete solution. In fact it has always been a serious question in my mind if the lightning arrester on the Niagara-Buffalo line accomplished anything at all toward continuity of service. There may have been some occasions when the arresters took care of lightning surges that might have caused damage and interruption of service without them; also there were other occasions when the failure of the arresters to quench the generator current caused service interruptions that would have been avoided if there had been no arresters. The use of lightning arresters on transmission lines is still a mooted question. In general it has been found that the higher the voltage of transmission, the less necessary lightning protection becomes. With the very high voltage used in some of our latter-day transmissions, the voltage strains caused by lightning are but little if any higher than the normal voltage strains. The higher the voltage used for transmission, the less necessary becomes lightning protection, due to the fact that the operating voltage requires so high an insulation. All this, however, was not known in 1896, and we at Niagara had to pass through the labor pains of the birth of this knowledge.

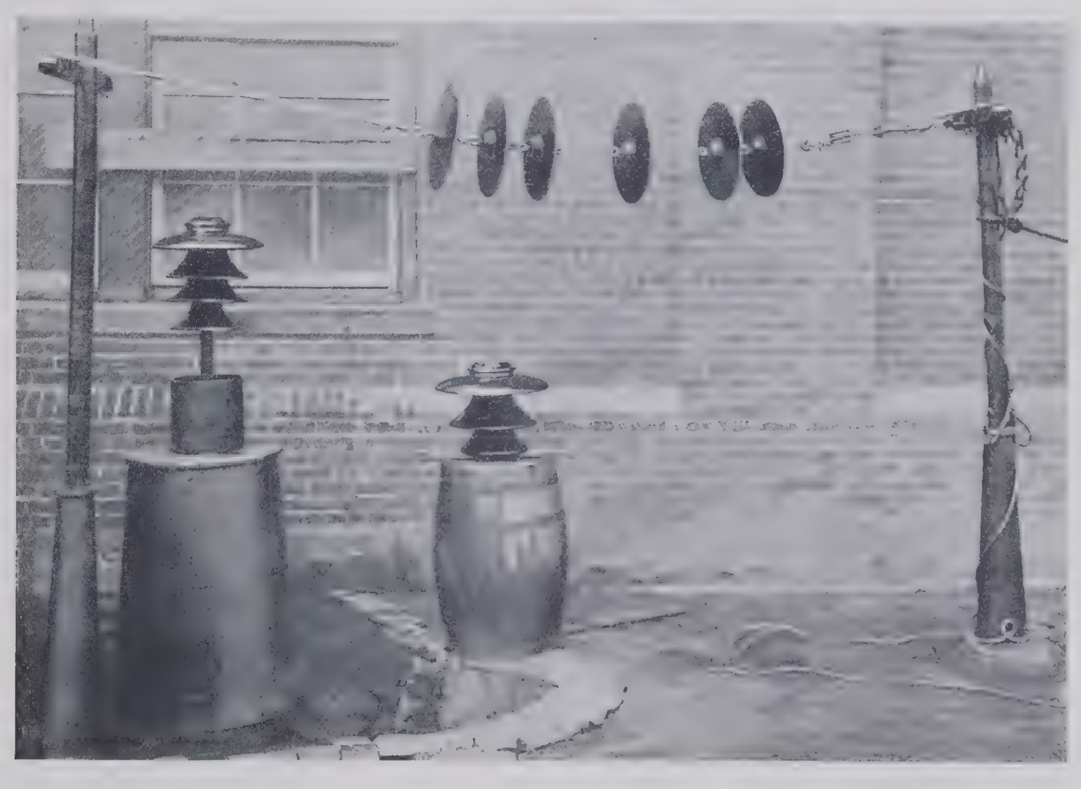
The design and construction of the first Niagara-Buffalo line incorporated one method of protection against lightning that proved disastrous. Theoretical considerations indicated that grounded guard wires over the transmission lines would be effective, at least to some degree, in shielding the transmitting conductors from lightning. Three such guard wires were installed on the original line. Unfortunately, however, the material selected for these guard wires was standard barbed fence wire. So long as the guard wires remained intact they were undoubtedly effective to a considerable degree in protecting the line. But the material of these guard wires was not equal to the strains put on them in this service and occasionally they would break and fall across the transmitting conductors below. This would cause a short-circuit and usually a complete interruption of service. The worst of it was that often service could not be restored until the broken guard wires had been found and removed. Guard wires, therefore, were not found to be conducive to continuity of service in this case. After the experience of a few of these guard wires being broken, the guard wires were removed.

In passing, I might remark that this experience has not shaken my faith in the efficacy of guard wires as protection against lightning. It is still my opinion that guard wires properly installed constitute the best protection available against lightning; however, the "properly installed" should be emphasized.

To recapitulate, lightning was probably the greatest single cause of service interruption on the Niagara-Buffalo transmission, partly because of the severity of lightning storms on the Niagara frontier and partly because of the insufficiency of knowledge in methods of combating the difficulty. Not a small part of this knowledge resulted from our experience on this particular transmission line. While we were not able to obtain perfect protection from lightning, the interruptions we were getting at the end of my six years' connection with the Niagara-Buffalo transmission were not so serious as at the beginning. We were continually getting the better of the problem of interruption by lightning. This is evidenced by a record of more than a year's operation without a single interruption of service from lightning or any other cause—a record that has been made by this Niagara-Buffalo transmission.

LINE INSULATORS

The line insulator constituted another problem that we on the Niagara-Buffalo transmission had to meet and meet with but little previous experience to guide us. The early transmission lines followed the practise already set by the telegraph. The only previous departure from this practise had been the Frankfort-Lauffen transmission in Germany during 1891. In that installation, power had been transmitted from a water-power at Lauffen to the city of Frankfort—a distance of about 100 miles. 30,000 volts was used in this installation—a voltage far above anything that had been used previously. The installation was not intended to be a permanent one. One of its main purposes was to advertise an exposition then going on in the city of Frankfort, and it was more or less of an experiment. The insulators used on this transmission were provided with an oil cup so designed that an oil-covered surface was interposed into the path of any leakage current over the surface of the insulator. At that time, it was not considered practicable to use any other type of insulator on so high a voltage. It is also noteworthy to observe that in its earlier proposals for the insulators on the Niagara-Buffalo line (made either late in 1893 or early in 1894) the Westinghouse Company proposed to use similar oil filled insulators. Apparently the oil filled insulator idea was later abandoned and both the Westinghouse and the General Electric companies proposed insulators of the general type later adopted. This is of interest as indicating the unsettled state of the transmission art at this early day. The drift of actual practise has been entirely away from the oil filled insulator. So far as I know, the Frankfort-Lauffen transmission was the only case in which oil filled insulators were ever actually used in power transmission, but they were seriously considered in 1893 or 1894 for use on the Niagara-Buffalo line.



TEST OF THE FIRST "SUSPENSION TYPE" STRAIN INSULATOR BY HAROLD W. BUCK, AT SCHENECTADY, NEW YORK, NOVEMBER 24, 1905. THIS INSULATOR REPLACED THE LARGEST SIZE OF PORCELAIN PETTICOAT OR PIN-TYPE INSULATOR

There were a number of designs of insulators tried out on the Niagara-Buffalo line. In every case the material was porcelain, but the shape, size and method of manufacturing differed. Among other types a large number of porcelain insulators made by the dry process were installed. These insulators were more or less porous and after some months of operation would absorb enough moisture to become slightly conducting. This in turn would lead to the burning of pins, cross arms and pole tops. Many difficulties of this nature were encountered and eventually all insulators of this type were taken down and rejected. To eliminate insulators of this character we developed the method of soaking them in salt water, using a salt water bath in which the insulators were partially immersed upside down and then filling the pin hole with salt water and applying the test voltage between the water in the pin hole and that of the bath. After this method of test had been adopted the defective porous insulators were quickly detected and rejected. In all about 40,000 of these dry process insulators were rejected in connection with this transmission. In many cases, however, the rejection did not take place until after the

STEEL POLE LINE FOR 60,000 VOLTS
Showing suspension type of insulation paralleling original 22,000-volt wood pole line with pin-type insulation, Niagara to Buffalo, 1924

insulator had been in service for some time and had had the opportunity to contribute its quota against us in our battle for continuity of service.

Except for our disastrous experience with these dry process insulators, the porcelain insulators we used at Niagara were fairly satisfactory. We knew more about the insulator problem after our six years' experience than we did before, of course, and the design and construction of porcelain insulators received a decided impetus from this experience. It is worthy of note, too, that one of the modern underlying types of insulators—the Hewlett-Buck insulator[1]—had it origin in connection with the Niagara-Buffalo transmission line. This particular type of insulator was not used, to be sure, on this first line but the problems of this line induced its conception.

Experimental Fuse-release 10,000-Volt Circuit Breaker

Melting of fuse releases a hinged arm 4 feet long which draws a momentary long arc. This type was used on the early Buffalo circuit

SWITCHES AND PROTECTIVE DEVICES

In 1896, protecting devices for transmission lines were conspicuous by their complete absence. The oil switch had not yet been conceived and there was no method known by which a short circuit on an operating transmission line of the capacity we had at Niagara could be opened without shutting down the entire system. The only overload protection we had at the beginning of operations was fuses. It soon developed that the fuse under these conditions was a menace and not a protection. The amount of power to interrupt was so large that the fuses of that day could not begin to interrupt a short circuit successfully. After this fact had been demonstrated by several sad experiences, all fuses were removed. The only alternative was so to arrange that the entire plant would be shut down in case of a short circuit. This was accomplished by causing the field circuit breakers on the generators to trip in case a short circuit came on and persisted. Since most of the short circuits occurred on the Niagara-Buffalo line, it soon became necessary to separate the transmitted load from the local load so that an interruption on one need not involve the other. There were a great many more short circuits on the transmission line than there were on the locally supplied load and the local load users objected strenuously to being shut down every time a short circuit occurred on the transmission lines. Hence the separation of the two loads.

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[1] Suspension type now almost universally used on high voltage lines.

Switchboard Control of The Niagara Falls Power Company, mcmxviii

The necessity of shutting down the entire system whenever a short circuit occurred pointed strongly to the necessity of securing a switch that was capable of interrupting a short circuit. No such switch existed at that time and the problem was put up to the manufacturing companies for solution. The General Electric Company started the development of the oil circuit breaker while the Westinghouse Company preferred a design that used long air breaks. As development proceeded and experience was accumulated it was apparent the General Electric Company had chosen the right path in this case. While air break switches might be satisfactory on the 11,000 volts that the Niagara-Buffalo line started with in 1896, it became evident as experience accumulated that with higher transmission voltages which was expected to be adopted within a few years, the air break switch would not be satisfactory. Even with the 11,000-volt transmission, their operation was far from satisfactory. I personally saw its operation on one occasion when a heavy short circuit caused the opening of one of these air circuit breakers. The arcs drawn were at least 6 feet long and maintained for nearly 15 seconds. The results obtained were so unsatisfactory that we went back to the method of interrupting the entire load in case of trouble.

One of the earliest models of the oil switch was brought to Niagara Falls by the General Electric Company for trial. The early trials indicated that this method of attack would be successful—and experience later proved this to be the case. Today, no one would think of using anything but an oil switch with voltages and amounts of power such as we were dealing with at Niagara. The General Electric Company was the first to make a move toward using oil to quench the arc in switching, but soon after it had proved successful the Westinghouse Company followed and today not only these two companies make this type of equipment, but many smaller companies also. The significant thing which I wish to emphasize here is that when the Niagara-Buffalo line began operations, there was no known method of successfully interrupting a short circuit. Our only method of procedure was to shut off the entire power supply under that condition. It was one of the handicaps of being a pioneer in the transmission game. This particular handicap was a very serious one since our battle at Niagara was to secure *continuity of service.* By the method of operation we were obliged to adopt, every short circuit on the transmission system meant a total interruption of power. It was, therefore, our endeavor to reduce the short circuits on the transmission line to a minimum.

Before leaving the subject of switching, perhaps a word concerning the first switchboard installed with the original generators might be in order. One of the items of this board was a series of air operated switches. When these switches were designed and built in 1894–1895 they were the best that the art afforded. It was confidently expected that they would be able to interrupt any load that might be thrown upon them. However, it required but a very brief experience after the first generators had been put into operation to realize that these switches would be totally useless to interrupt short circuits. They were used as synchronizing and disconnecting switches but beyond that they were useless.

In passing it might be observed that this problem of interrupting short circuits on the very large capacity high voltage modern transmission lines has proved to be one of the most difficult that the transmission engineer has met. The oil switch has proved the best means of meeting this problem that has been found, but even the largest and most powerful oil switch made is taxed to its utmost with some of our larger power systems behind it. Continuity of power supply requires that some means be used to disconnect defective portions of a transmission system and allow the remainder of the system to go on supplying service to the unaffected portions of the system. The need of such a switch was recognized in the early days of the Niagara-Buffalo transmission but we had to struggle along without it.

INTERRUPTIONS FROM MISCELLANEOUS CAUSES

Two other causes of service interruption were met on this Niagara-Buffalo line, viz., accident and malicious mischief. While accidents were not common, they did occur occasionally. For instance, on one occasion a dredge operating in the canal, along which ran the transmission line, raised its dipper into the line, thereby short circuiting the line and temporarily shutting off Buffalo's power. On another occasion, a cat crawled in behind the lightning arresters in the step-up transformer station and caused a complete short circuit and shut-down. Another very peculiar case occurred when a gang of men were cleaning the right-of-way from trees. A tree being felled, struck the end of a crooked limb lying on the ground and cause it to ricochet into the air; by an unlucky chance it fell across the transmission line and lodged there. The limb was green and just conducting enough to carry some current from conductor to conductor. The limb on the conductors confined this current to the point of contact and the burning continued until the transmission conductor itself was entirely burned apart and fell to the ground. This accident not only interrupted power supply to Buffalo, but it completely disabled that line until repairs could be effected. On still another occasion lightning caused an arc to form between the transmission conductor where it emerged from the step-up sub-station at Niagara and the edge of a metal canopy that had been erected to protect the conductors at their point of entry. This arc continued until the conductor was burned in two.

Some little trouble was caused by malicious mischief makers. The ubiquitous small boy found that he could cause a very spectacular display of fireworks by throwing a piece of wire over the transmission line. He little realized that he thus deprived momentarily a whole city of its power supply. Proper co-operation with the local police authorities along the line reduced this mischief to a minimum.

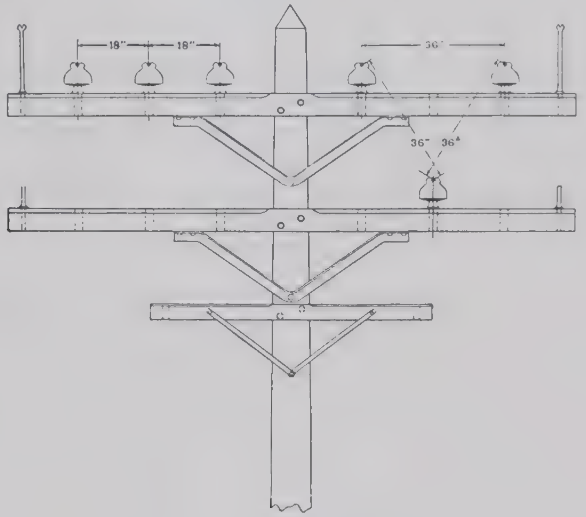
I might go on indefinitely giving instances of the difficulties that we encountered on this early power transmission. They all lead to one conclusion; we were pioneers and we suffered the fate of all pioneers. The road we were traveling was not yet illuminated by the light of experience. We had to grope our way. We were not wholly unsuccessful in lighting the way for others to follow. The Niagara-Buffalo transmission was a success both from a financial and from an engineering standpoint. The battle for continuity of service was waged and won. It has always been a matter of no little self-satisfaction that we at Niagara have helped to blaze the trail that since then has become a much traveled highway.

DESCRIPTION OF EARLY POLE LINES TO BUFFALO

The following data regarding the early lines are taken from a paper entitled *The Electric Transmission of Power from Niagara Falls* read by L. B. Stillwell before the American Institute of Electrical Engineers at its annual convention at Buffalo, August 23, 1901:

> In the first pole line constructed by Mr. J. G. White, the poles were of Canada cedar varying in length from 35 to 55 feet and set in the ground to depths varying from 6 to 8 feet. The cross arms were of Georgia pine 12 feet long and 6 inches in section. The poles were spaced about 70 feet apart except on moderate curves where they were

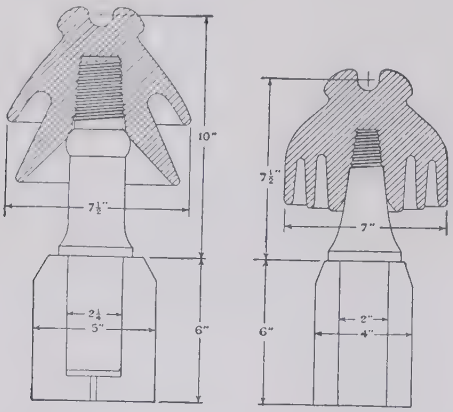
somewhat closer. This pole line was designed to carry 12 conductors of 350,000 c. m. section. The conductors were of copper having 19 strands and weighing a little more than one pound per linear foot. Only six of these conductors constituting two three-phase circuits were erected and the conductors of each of these two circuits were originally side by side on the upper cross arm. In each circuit the distance between the central conductor and each of the other two conductors was 18 inches. Experience demonstrated that it was a mistake to place the three conductors constituting a circuit on the same horizontal plane and only 18 inches apart as shown on the left in the accompanying figure. This arrangement proved very tempting to mischievous boys who repeatedly short-circuited the line by throwing across it short pieces of wire which they succeeded in lodging across two or more of the conductors. The resulting short-circuit continued to blaze along the line until the power was cut off at the falls. The arc always traveled away from the power-house. The trouble was finally cured by triangling the wires bringing them into the position shown at the right of the pole in the accompanying figure.



Cross-arms of Pole Line Showing Insulators in Place
Left, insulators on horizontal plane; right, insulators as rearranged in triangular position

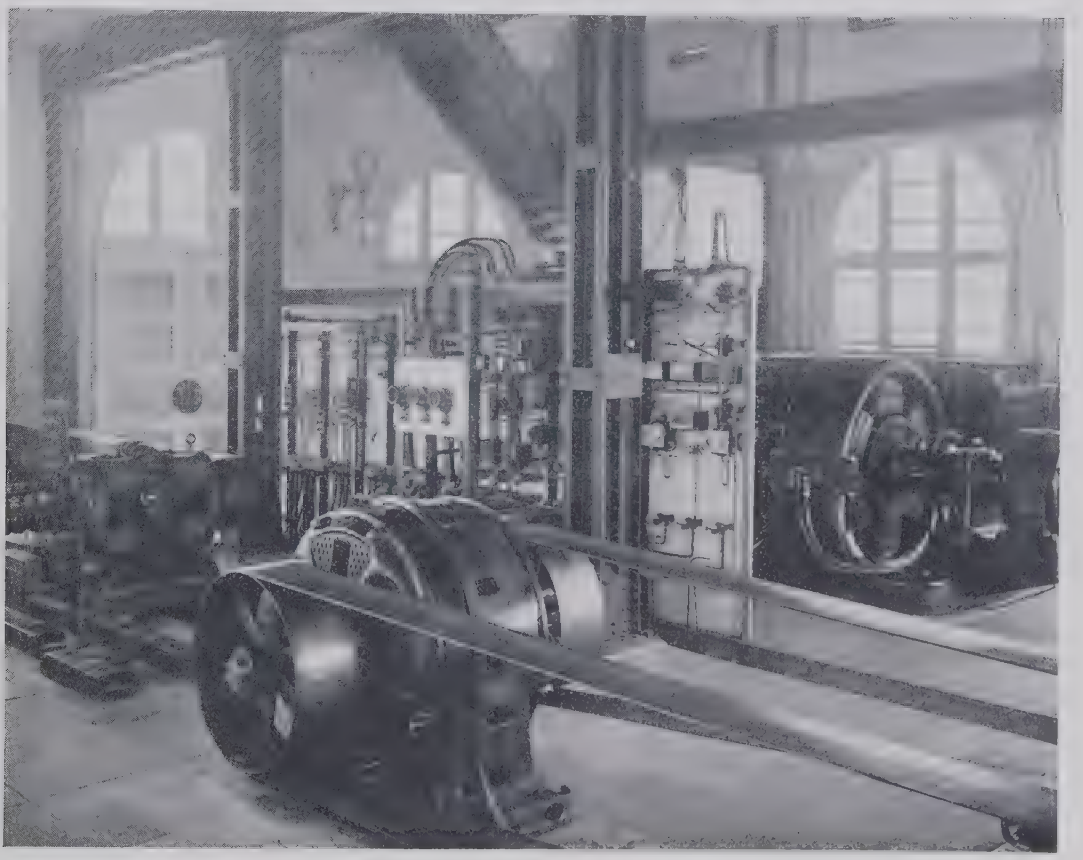
A new pole line was undertaken in the year 1900 and it was decided to increase the potential on the overhead transmission lines from 11,000 to 22,000 volts. The new pole line differed radically from the old one. The length of the span was doubled being increased from an average of 70 feet to about 140 feet. The unusually close spacing of poles in the old line is explained by the fact that it was assumed that during sleet storms ice might cover the conductors to a radial length of half an inch, which, if it did actually occur, would of course greatly increase the pressure, tending to overthrow the line during wind storms, which upon the Niagara frontier are often very severe. But experience during a number of winters has demonstrated the fact that ice never adheres to the power circuits while they are traversed by the working currents. This result is due in part presumably to the heating effect of the current and in part perhaps to static repulsion. It is certain that dry snow is statically repelled by the charged conductors, and I think it probable that this effect also helps in the case of sleety rain. In the case of the new line, calculations of the effect of wind pressure were based upon the projected area of poles, cross arms and conductors, but with no allowance for a covering of ice. Experience had shown that mechanically the weak point in the construction of the old line was the junction of pin and insulator, and for the new line a new pin and new insulator were specially designed. Cross sections of the old and new types are shown below. The old pin at the top is but 7/8 inch in diameter, while the new one is 1½ inches. On the old pin but six threads engage with the threads in the pin hole of the insulator while in the new one nine threads are used. It is a singular fact that almost every power circuit hereto erected in the United States has used an insulator pin of the same diameter at the top as the standard Western Union pin which was designed for a very different kind of service. Without going further into detail, it is sufficient to say that notwithstanding the fact that the length of span is doubled, the insulators of the new line are relatively much more securely fixed upon their pins than are those of the old line.

Aluminum conductors of 500,000 c. m. section are used for the new line. The old and new pole lines follow the same route from the power-house to a point a short distance beyond Tonawanda where they diverge, the new line from the point named to the terminal house which is located just inside the city line at Buffalo being approximately three miles shorter than the old lines.



Cross-sections, Contrasted Types, Insulator and Pins
New type, left; old type, right

In a letter to the president of The Cataract Construction Company, January 7, 1893, Mr. Stillwell had stated that the efficiency that could be guaranteed for the transmission from Niagara to Buffalo was 88 per cent. A comparison of wattmeter readings at the two ends of the line during June, 1901, showed a net transmission efficiency of 88.4 per cent.



Tonawanda Sub-station Rotary Converters, and Motors Driving Arc-light Machines

TRANSFORMERS FOR THE EARLY TRANSMISSION LINES

The transformers for the original line were of the air-cooled or air-blast type and were supplied by the General Electric Company. At the generating station the transformers were in pairs transforming from 2200 volts, two-phase to 11,000 volts or to 22,000 volts, three-phase, each pair having a capacity of 2500 horse-power.

For the second line oil-insulated water-cooled transformers were supplied by the Westinghouse Company. They were in pairs, each pair having a capacity of 5000 horse-power and corresponded in ratio of transformation to the transformers already installed.

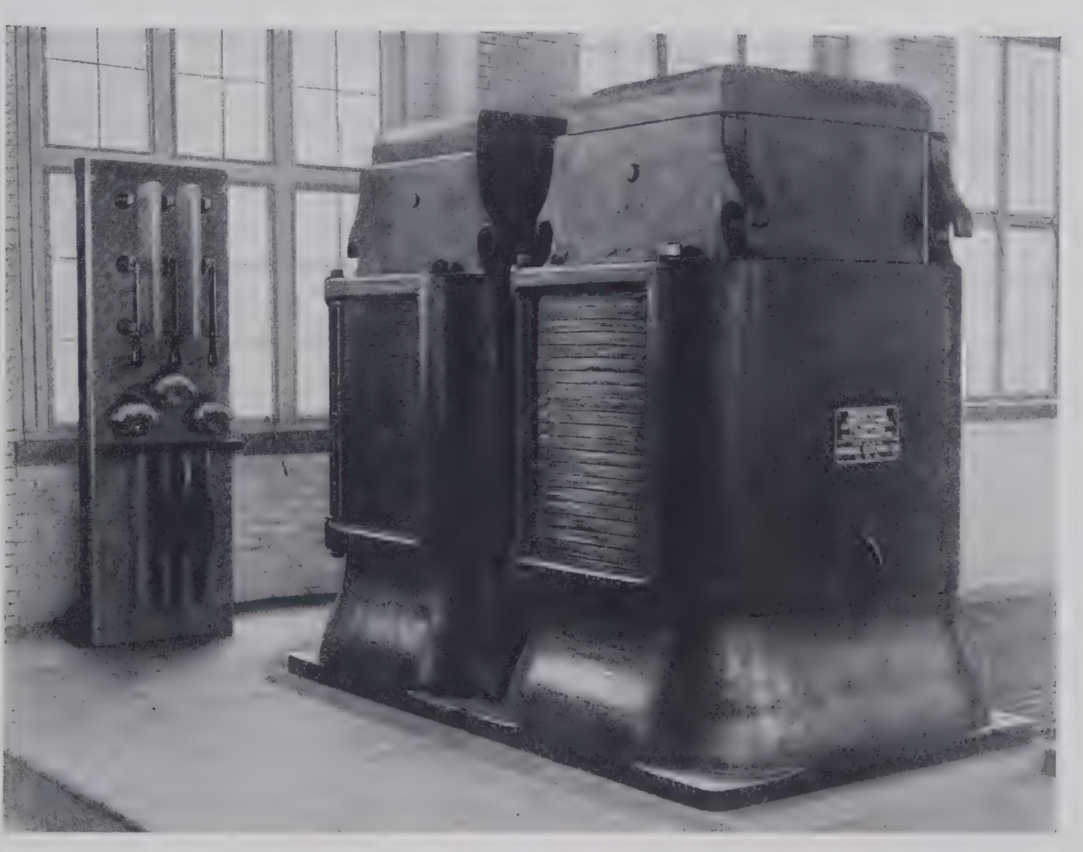
CANADIAN POWER FOR BUFFALO: NEW TRANSMISSION LINES

The first transmission line which began service in 1896 and the second line constructed four or five years later for transmitting power from the stations of The Niagara Falls Power Company to the city line of Buffalo and thence by cables to sub-stations in the city have been described.

Tonawanda Sub-station

Appreciating the importance of a second source of power on the Canadian side of Niagara River, independent of the original plant at the American Falls, as a further assurance of continuity in the supply of electric power at Buffalo, an opportunity was availed of to secure a franchise through the purchase of the control of what was subsequently termed the Canadian Niagara

Power Company, and to obtain the necessary consent of the Canadian and Provincial governments for the location and construction of the Canadian power-house within the limits of the Queen Victoria Niagara Falls Park. 10,000 horse-power from this plant was delivered January 1, 1905, to The Niagara Falls Power Company.



Air-blast Transformers for First Buffalo Transmission Lines

Taken one week after first power was delivered to Buffalo, November 15, 1896

The power transmission line on the Canadian side was authorized early in September, 1905, as a two-circuit three-phase 22,000-volt line, of an approximate capacity of 25,000 electric horse-power by the use of both its 12,500 electric horse-power units in commercial operation at that time.

The route of this right-of-way previously purchased in fee, extends from the Canadian power-house along the line of the old Erie and Niagara Railroad Company to Fort Erie, Ontario.

The terminal station A in Buffalo had at this period about reached the limit of its transforming capacity of 40,000 horse-power, 30,000 for distribution and 10,000 held in reserve to protect the continuity of the service.

Terminal house B was erected in 1906 to receive the transmission cables from the Canadian Niagara Power Company's plant by pole line along the bank of the Niagara River to Fort Erie, where the cables crossed the Niagara River on suspension towers and entered the new terminal house.

Air-blast Transformers at Niagara for the Early Transmission to Buffalo

The outdoor station, an up-to-date construction, has a capacity of 200,000 horse-power and facilities of distribution through other sub-stations and many miles of conduits and cables.

The company took over in 1922 the electrification of the streets of Buffalo thereby replacing approximately 10,000 lamps of the old system of gas lighting.

TRANSMISSION LINE ACROSS GRAND ISLAND

Soon after the Federal Power Commission issued its license[1] to The Niagara Falls Power Company, March 2, 1921, and thereby confirmed to it the rights of water diversion for fifty years, the company proceeded with its contemplated development of 200,000 electric horse-power, including a new transmission line by way of Grand Island, to Buffalo, a line distance of 10.5 miles from the Echota sub-station to terminal C of the Buffalo General Electric Company.

Terminal Station (House B), Buffalo, with Transmission Tower

This line is officially described as consisting of two 3-conductor circuits of 500,000 circular mil copper cables strung on steel poles or towers. At the upper crossing of the Niagara River to Grand Island, the channel span is 1800 feet and two anchor spans are 960 feet each. The two suspension towers are 300 feet high and the two anchor towers 65 feet high. At the lower crossing, from Grand Island over the United States branch of the Niagara River, to the mainland, there are two channel spans of 1600 feet each and two anchor spans of 900 and 814 feet respectively. The three suspension towers are 230 feet high and the two anchor towers are 65 feet. The line is operated at 60,000 volts, at which potential each of the two circuits will carry 65,000 horse-power. It is so constructed that with slight changes and additional insulation it may be adapted for 110,000 volts, increasing carrying capacity to more than 100,000 horse-power per circuit.

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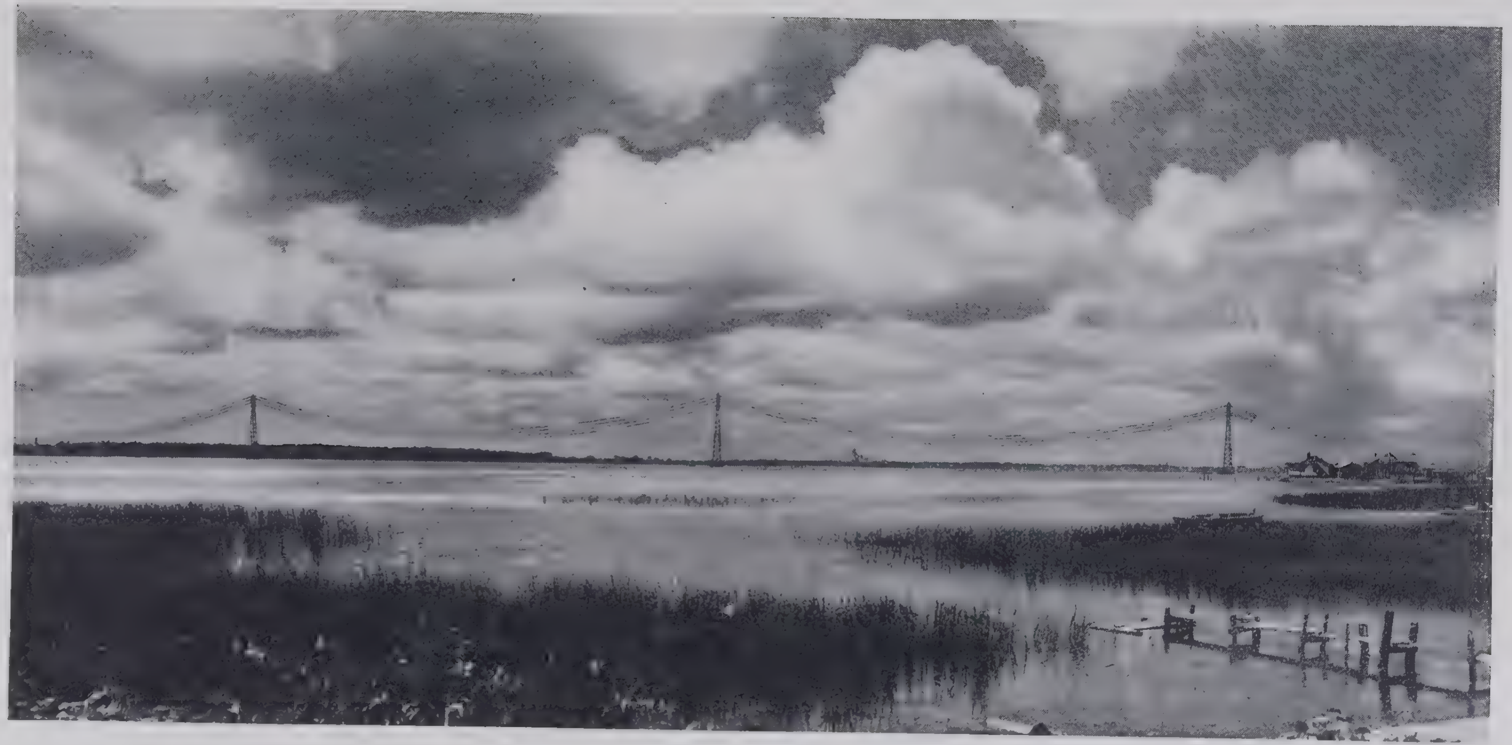
[1] The Niagara Falls Power Company has the distinction of having received the first license granted by the commission.

Transmission Line, Niagara to Buffalo via Grand Island,
Crossing the Niagara River

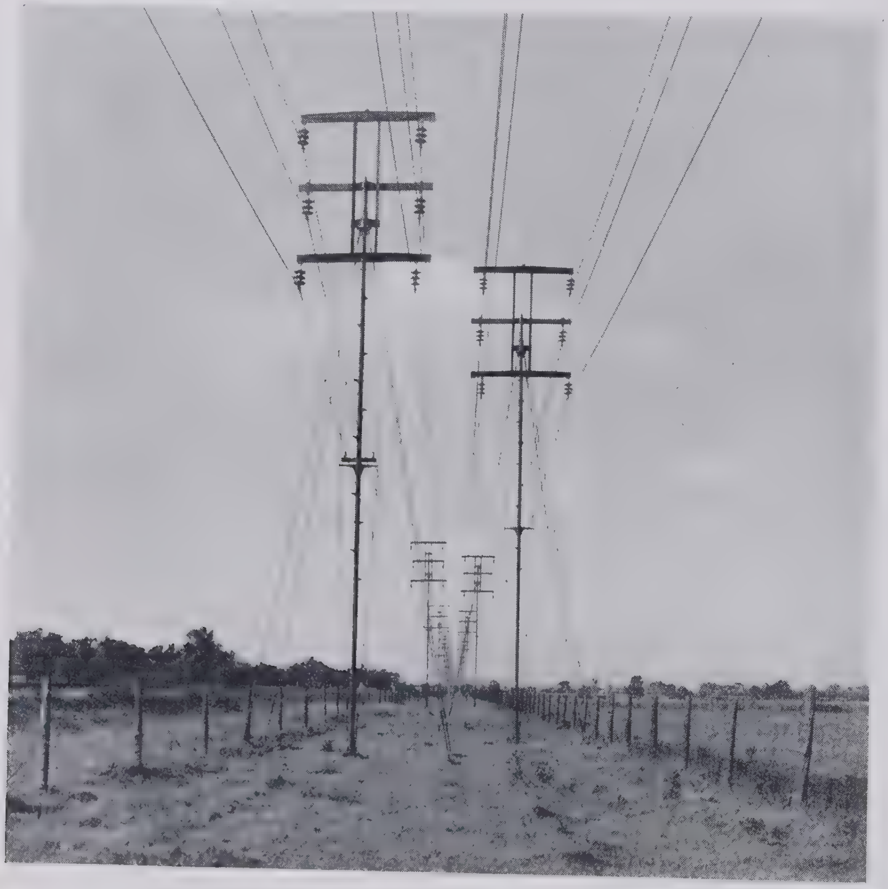
The voltage of the Canadian transmission lines to Buffalo was raised in 1925 from 22,000 to 40,000 volts.



Transmission Line to Buffalo via Grand Island at Lower Crossing of Niagara River

All of the company's transmission lines built since the merger in 1918 are equipped with suspension insulators. The lines are protected from lightning by two steel guard or ground wires attached to the tops of the poles.

About twice a month a man drives over the right-of-way in an automobile and reports in by telephone anything requiring immediate attention.

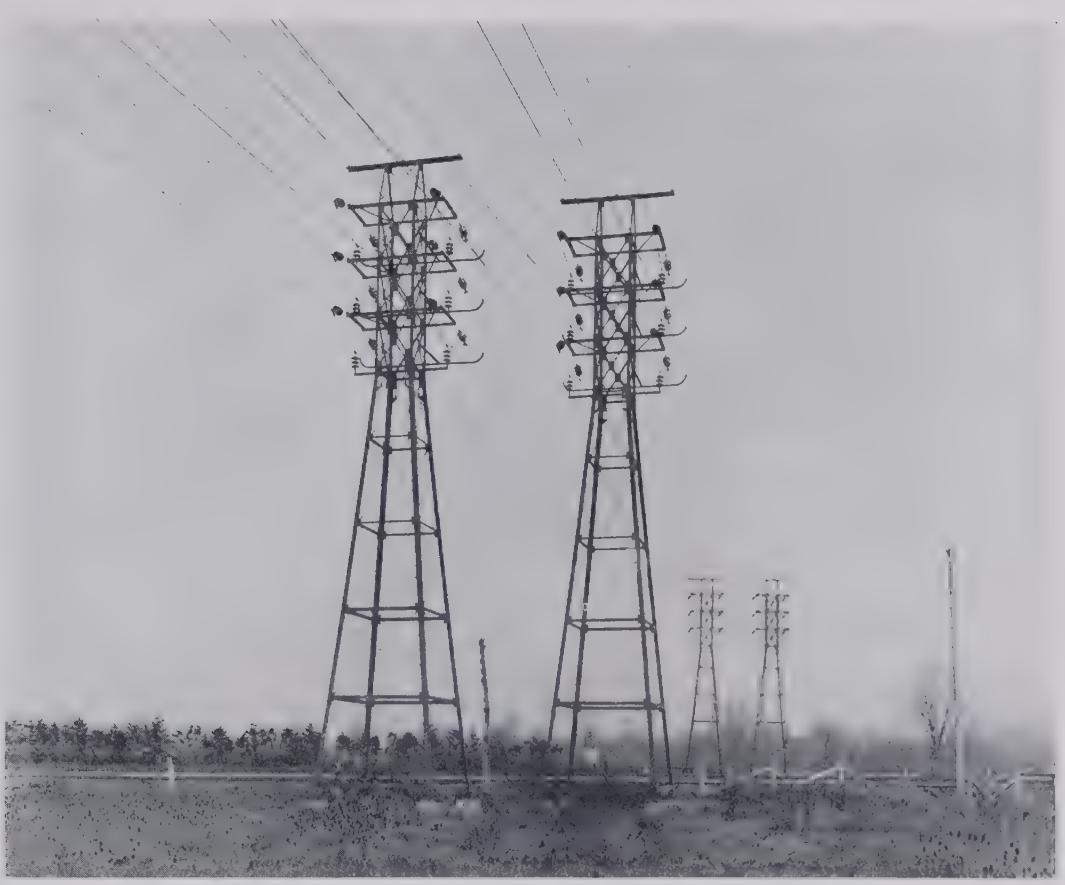


Pole Lines from Canadian Power Station to Buffalo

Original pole had three pin-type insulators, one on top and two on a single cross-arm. Recent reconstruction adds two cross-arms and provides for six wires supported by suspension-type insulators

SUBSEQUENT DEVELOPMENT OF TRANSMISSION SYSTEM

The pioneer transmission lines to Buffalo, which began the delivery of power on November 15, 1896, have been reconstructed or replaced as advances in the art have permitted the use of higher voltages and the transmission of power to greater distances. Wooden poles closely spaced have been succeeded by iron poles and then by steel towers, with their long spans of transmission cables. Porcelain insulators were greatly improved in material and form and larger pins were adopted. Then at Niagara was developed the underhung insulator, making practicable voltages far above the 60,000 or 70,000-volt limit fixed by the pin-type insulator, making the greatest step in power transmission since 1896.



Niagara-Buffalo Transmission Circuits Replacing the
Original Wood-pole Lines

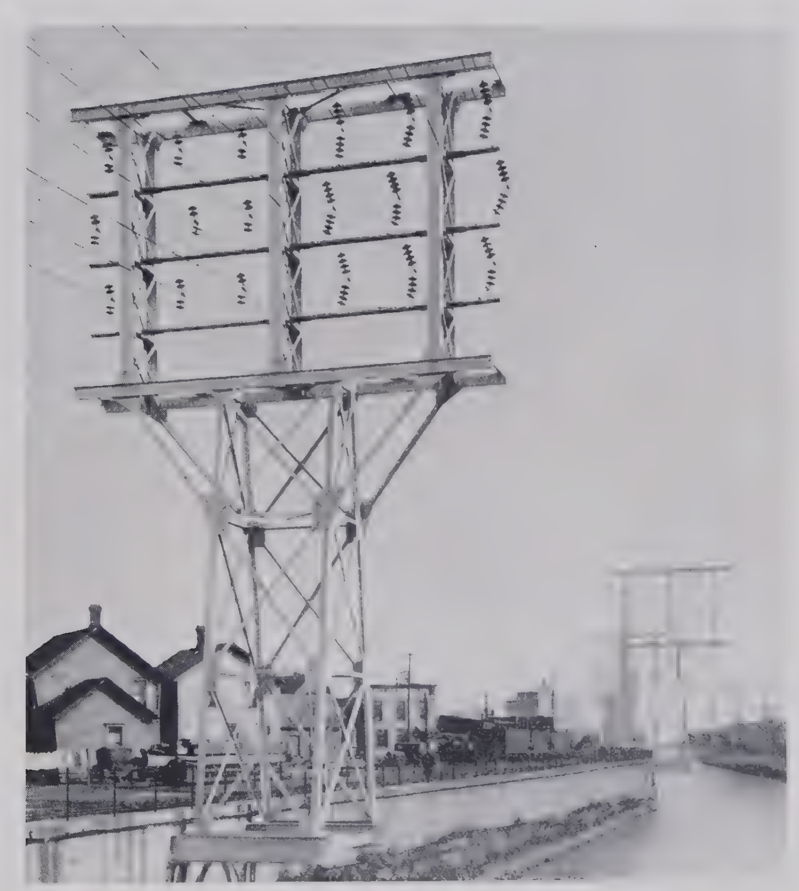
From the initial pole line transmitting during its first year of service a thousand horse-power at 11,000 volts, a distance of 22 miles, has grown a system of circuits of different voltages for supplying service to an area 300 miles long and 100 miles wide.

This high-tension transmission system embraces an aggregate of 1000 miles of circuits insulated for 110,000 volts and nearly an equal length of circuits insulated for 4000 volts or more.

This transmission system is the *sine qua non* of the effective utilization of Niagara power and of the combination of power interests represented in the Buffalo, Niagara and Eastern Power Corporation. It makes possible the combining of physical properties including hydraulic and steam-driven electric plants aggregating three-quarters of a million horse-power in serving half a million homes. It also makes possible interconnection and interchange of power with other neighboring power systems, in the United States and in Canada. The extent of the transmission system controlled by the Buffalo, Niagara and Eastern Power Corporation, as well as the adjoining systems with which it may be interconnected, are shown on page 354, Chapter XVI, Volume One. Further details with regard to the power-plants, transmission lines and distributing systems of the company will be found in the first annual

Tower Raising Automobile Truck, 1924, and Transmission Lines from Power Station report of the company, a portion of which is reprinted in Chapter XVI, Volume One.

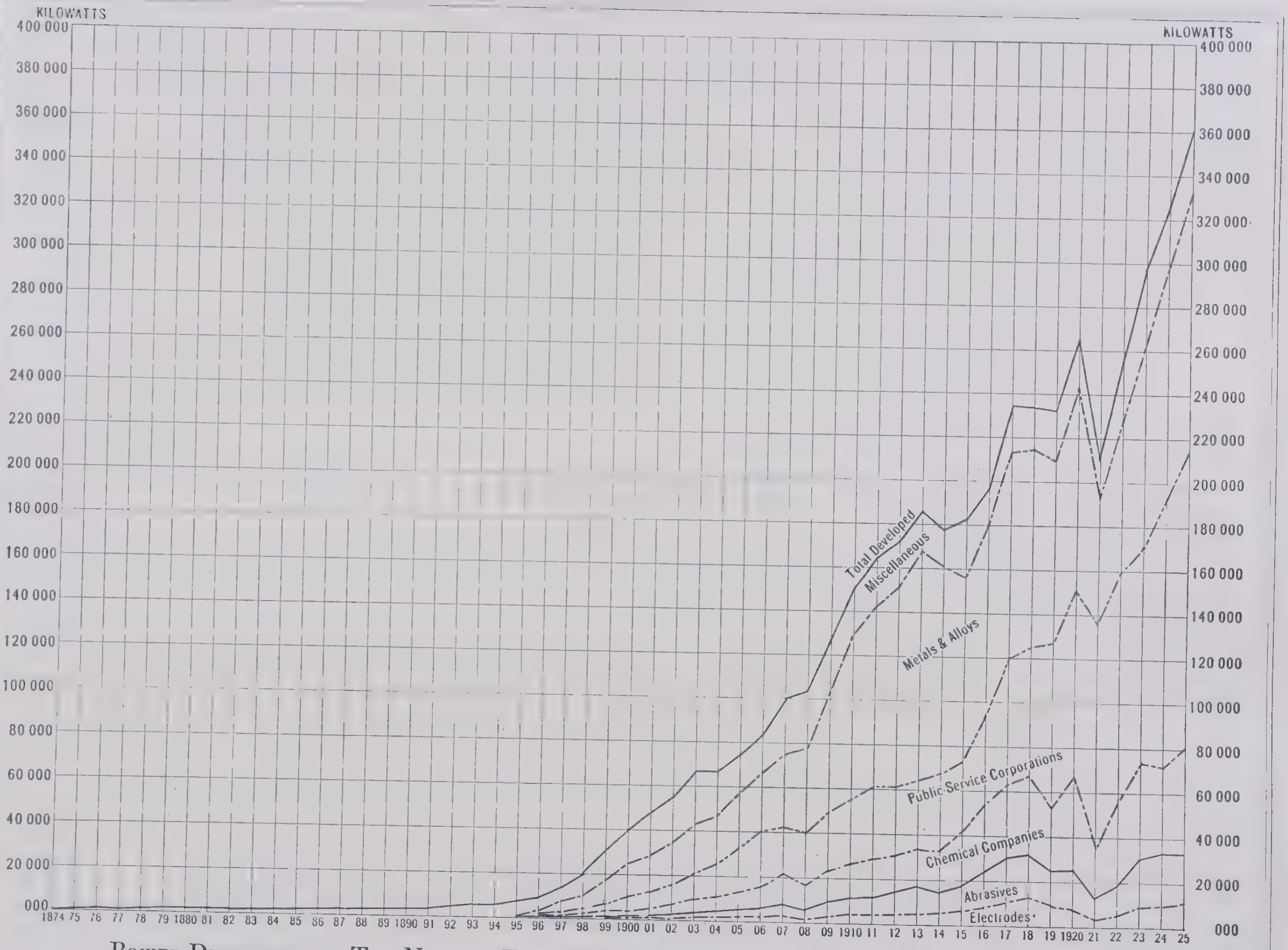
The present transmission system is simply an expansion and extension of the method employed on the first Niagara-Buffalo transmission line, the original line for the first large scale commercial use of polyphase current for power transmission. The original choice of this method has been justified not only in its use in the growth and development of the Niagara system, but in its universal use throughout the world. Furthermore, no method is known by which power transmission and distribution, on the scale it is conducted today, could be carried on, other than that which was initially selected for Niagara.



Circuits from Niagara Power-house, 1925

LIGHT, HEAT, POWER ELECTROCHEMICAL AND METALLURGICAL INDUSTRIES

Chapter XXVI



POWER DEVELOPED BY THE NIAGARA FALLS POWER COMPANY, AND ITS CONSTITUENT AND ALLIED COMPANIES, AND ITS DISTRIBUTION AMONG VARIOUS CLASSES OF SERVICE (1874–1925)

LIGHT, HEAT, POWER ELECTROCHEMICAL AND METALLURGICAL INDUSTRIES

CHAPTER XXVI

TODAY, all of the Niagara power-plants are linked together for service as a gigantic operating unit. Their output is measured in billions of kilowatt hours per year. This vast reservoir of power grows greater each year as new applications of electricity are developed and the constant load is raised.

The Niagara power system is interconnected with other great power sources to the north, the east, the south and the west and constitutes the hub of a coordinated international super-service totalling two million horse-power.

According to reiterated published statements it long has been the purpose of the Niagara power system "to render the most dependable service, to the greatest possible number of people, within economical transmission distance, at the lowest cost consistent with fair wages to the labor and the capital employed."

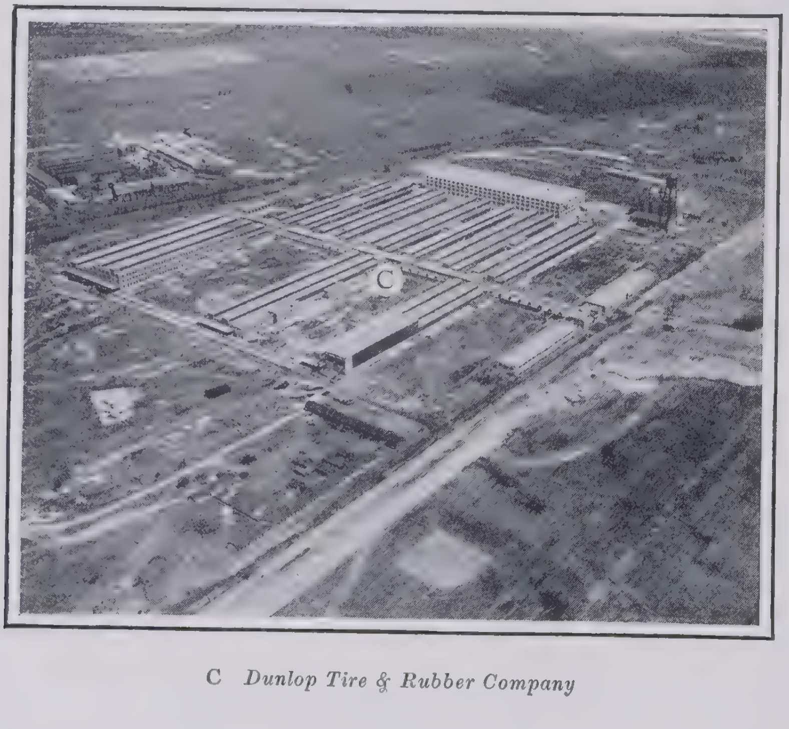
The use of Niagara power now is about equally divided between direct and indirect service. By direct service is meant the ordinary applications of electricity in the home, the office, the store, and the factory for light and power. Indirect service is the use of electricity in the field of electrochemistry, producing basic materials which are essential to the successful operation of other industries.

DIRECT SERVICE

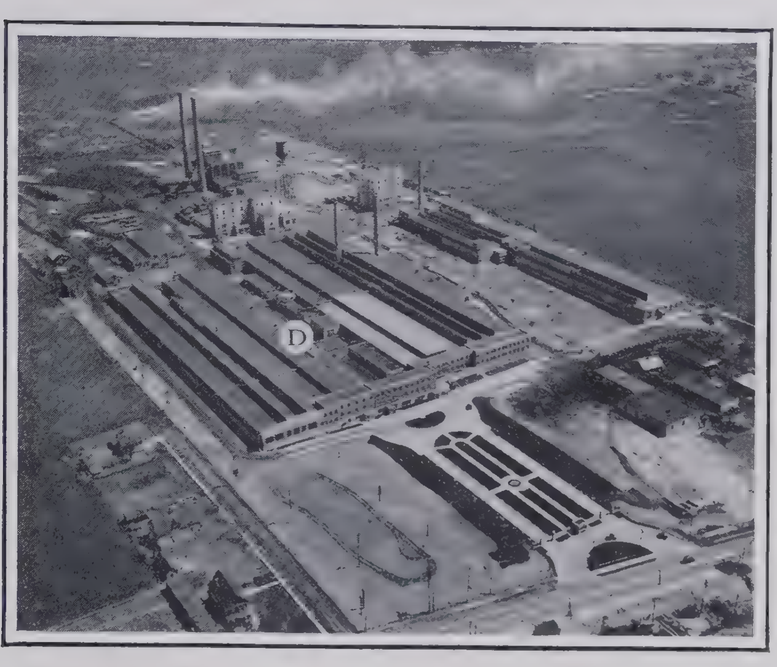
More than two million people live in the seventeen counties embraced in the area now reached by Niagara power. About one-half the population of the Empire State, outside of Greater New York, draw their electric service from this great pool of power by the simple pressing of a button, or by the closing of a switch. It serves, without favor, communities large and small. It lights with equal brightness the city street and the rural highway. It lessens labor on the farm, and helps to solve the servant problem on the avenue. The humblest home and the proudest palace are alike well served. It cooks and cools, washes and irons, cleans and scrubs, saws the wood, milks the cows, pumps the water, and works its wonders in a thousand ways for the multitude of people it serves.

So wide-spread is the use of Niagara power today, and so diversified its applications, that it is impracticable to attempt to tell in detail about the customers who receive direct service. Large cities like Buffalo and Syracuse, other cities like Auburn, Jamestown, Dunkirk, Lockport, Niagara Falls and Batavia; and hundreds of lesser cities, villages, and towns all look to Niagara for dependable electrical service.

A *Donner Steel Company*
B *National Aniline & Chemical Company*



C *Dunlop Tire & Rubber Company*



D *Du Pont Fibersilk Company*

E *Wire Wheel Corporation of America*
F *The Pierce-Arrow Motor Car Company*
G *American Radiator Company*

The largest retail distributor of Niagara power is the Buffalo General Electric Company. On December 31, 1926, its domestic and commercial users numbered 162,067 with a total connected load of 515,254 kilowatts. The entire continuous load of the Buffalo district is supplied from Niagara Falls, only the peak loads being carried on a steam electric station, which also serves as a standby station for emergency service for the Niagara system.

The Syracuse Lighting Company serves a population (December 31, 1926) of 265,000 people through 59,707 meters with a connected transformer capacity of 100,803 kilowatts and obtains its entire electrical supply from the system of the Niagara, Lockport and Ontario Power Company, the wholesale distributors of Niagara power.

Other large retail distributors of electrical energy, purchasing substantial blocks of power from the Niagara, Lockport and Ontario Power Company, are the Western New York Utilities, Incorporated, of Batavia; Rochester Gas and Electric Corporation of Rochester; Empire Gas and Electric Company, operating in Geneva, Auburn, Seneca Falls, Lyons and adjoining territory; and New York Central Electric Corporation, operating in Hornell, Warsaw, Perry and nearby towns and villages.

At the end of the year 1926 Niagara power was sold in bulk to 27 distributing utilities, 17 municipalities, 17 electric urban and interurban railways, and furnished lighting for 28 cities and villages and 61 lighting districts, through the agency of the Niagara, Lockport and Ontario Power Company.

To render this direct service reaching 80 per cent of the 500,000 homes located in the Niagara power zone, some 300 miles from east to west and 100 miles from north to south, there is employed a network of transmission lines which blankets western and central New York State. This system has approximately 2000 miles of transmission circuits insulated for high voltages.

Wherever Niagara power has gone the use of electricity has increased and its cost has decreased.

Buffalo has relatively the greatest annual kilowatt hour consumption of electricity for domestic use of any city in New York State if not in the entire United States. During 1926 it averaged 734 kilowatt hours per domestic user. The domestic service in Buffalo was rendered at a cost to the consumer of an average of $.0344 per kilowatt hour. In other words the average cost of electricity per wired home in Buffalo was $25.25 for an entire year's service.

The influence of cheap Niagara power is also reflected in the ordinary commercial and industrial uses in the Buffalo district which produces a great diversity of fabricated products. Sixty-four per cent of the articles enumerated in the United States Census of Manufactures are made on the Niagara frontier. The high ratio of power to worker is reflected in high production and increased earning power of labor.

In a condition of society where each man's livelihood depends upon his own unaided efforts, the state of civilization necessarily must be low, and the majority of the people in poverty and misery.

Conversely, the state of civilization will be the most advanced, and the general well-being the greatest, where the ratio of usefully employed power to population is the highest. Such a condition obtains in the Niagara zone.

INDIRECT SERVICE

Synchronous with the development of hydro-electric power at Niagara was the discovery and laboratory development of many materials that are now essential basic materials in American industry. Aluminum, artificial abrasives, calcium carbide, artificial graphite, ferro-alloys, and many other now common things were only laboratory curiosities when work was started upon the large scale production of Niagara hydro-electric service, during the last decade of the last century.

Such an authority as Frank J. Tone, president of the Carborundum Company said:

> The development of Niagara power in 1895 marked the beginning of the electric furnace art. It stands today as one of the big factors in our industrial life. Up to 1895, when Charles M. Hall came to Niagara, the aluminum industry depending on steam power had given little promise of commercial success. Its almost incredible development has been due to the impetus of Niagara power. Dr. E. G. Acheson with a 150 horse-power furnace operated by electric power generated from steam had made a commercial failure of carborundum. Coming to Niagara in 1895 he was at once enabled to found the artificial abrasive industry. Willson, the inventor of calcium carbide, was working at Spray, North Carolina, with a 200 horse-power furnace. Today there are furnaces at Niagara making as much carbide in a day as the former furnace produced in a year.
>
> With the technology of these great industries—aluminum, calcium carbide, abrasives, ferro-alloys, silicon and graphite—all are familiar, but few realize their economic importance or to what extent the industrial and the metallurgical arts are indebted to Niagara power for their development.[1]

While the ordinary uses of Niagara electricity, which are made available by public service companies, are familiar to all the world and the value of such uses is recognized and appreciated, the indirect service through the production of basic materials by the electrochemical industries is just as efficacious and more far-reaching.

Electrochemical plants may be divided into two general groups—those employing electrothermic processes and those using electrolytic processes.

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[1] Transactions of the American Electrochemical Society, Volume XXIX, 1916.

The electrothermic process uses a high temperature in an electric furnace to combine two or more natural elements to produce a new product; for example, carborundum is carbon and silica fused.

The electrolytic process uses electricity to break down a natural element producing two or more new materials; for example, caustic and chlorine are produced by the disintegration of salt.

Practically all the electrochemical industries demand a constant twenty-four hour supply of electricity. Whereas in ordinary manufacture, power represents less than two per cent of the total fabricating costs, it frequently mounts up to from 20 to 40 per cent of the total costs in the electrochemical industries.

Niagara is the greatest single source of constant water-power in the United States. Here is power stupendous in magnitude, easily developed, at a construction cost so relatively low that electric energy cost to customers is the very lowest.

Niagara was a magnet to which was attracted the new born of the electrochemical family.

Electrochemistry has wrought an industrial revolution. Its processes have more or less completely displaced the older, slower and more costly chemical methods employed in the manufacture of such things as caustic soda, chlorine and phosphorus compounds, or the isolation of such metals as sodium, potassium, calcium, magnesium and aluminum.

ALUMINUM

The first to seek this cheap and dependable power source was the aluminum industry. On February 10, 1886, Charles M. Hall, after many months of experimenting, succeeded in producing electrolytically the first globules of metallic aluminum, and within the same month (February 23) made an additional discovery that established the basis of his renowned invention.[1] It was not until 1888, however, that production on a commercial scale was attempted in a small plant in Pittsburgh employing five workmen. The development of the demand for aluminum, and the expansion in the development of an abundant and reliable supply of low cost hydro-electric energy at

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[1] It is an interesting coincidence that in February and March of 1886 three enterprises had birth, each of which, developing independently, were united nine years later for the furtherance of one great purpose. In the month following Mr. Hall's discovery (March 16, 1886), Stanley's alternating-current plant for experiment and demonstration began operation at Great Barrington, Massachusetts (see Chapter XXII, page 187, Volume II) and on the 31st of the same month, the New York State Legislature granted the charter which was the legal beginning of The Niagara Falls Power Company. (See Chapter XI, Volume I.) In the summer of 1895, The Niagara Falls Power Company began commercial operation generating alternating current and its first customer was the Pittsburgh Reduction Company, manufacturing aluminum by the Hall process.

Niagara brought about the natural result of a transfer of operations from Pittsburgh to Niagara Falls of the Pittsburgh Reduction Company, now the Aluminum Company of America. It was on August 5, 1895, that the first aluminum was made at Niagara—that being the first use of Niagara power in the electrochemical industry. A year later the capacity of the first plant was doubled and a second plant built. Later still another plant was erected and the capacity of all plants has multiplied many times since.

Aluminum is produced by the following process which emphasizes the necessity for continuous, reliable and low cost electric energy.

The ore, bauxite, having been refined or concentrated to the oxide of aluminum, commonly termed alumina, is reduced in a large rectangular pan-shaped electric furnace lined with carbon. Into this furnace is first introduced a bath or dissolving medium, consisting of cryolite, which is sodium-aluminum fluoride. Large carbon rods, which constitute the anode, are lowered into the furnace to within a short distance of the carbon lining, which constitutes the cathode. Electric current is then turned into the furnace and an arc is created between the anode and cathode, the heat from which melts the bath. Alumina is then introduced into and dissolved by the bath. The same electricity which affords heat for keeping the bath molten, also electrolyzes the metallic aluminum out of the bath and alumina solution, with the result that aluminum is deposited on the cathode, that is, the bottom of the furnace, from which it is drawn off periodically. The process is continuous, no interruptions occurring until some portion of the apparatus becomes so worn as to necessitate repairs. As the aluminum is electrolyzed out of the bath, further alumina is introduced, and as the bath becomes weakened, other cryolite is introduced to maintain the bath at its proper strength. The aluminum is drawn off into pigs, which are remelted and cast into small casting ingots or ingots designed for rolling purposes, and the rolling ingots are thereafter rolled into the aluminum sheets of commerce.

No industry depends exclusively upon aluminum unless it be that of cooking utensil manufacture, in such factories as produce nothing but aluminum utensils. It would, however, be practically impossible to eliminate aluminum from the world of metallurgy today, since it has become the principal light metal of commerce.

Perhaps the industry most dependent on aluminum production is the automobile industry, which consumes, at the present time, about 40 per cent of the entire aluminum production of the country. In this connection, it is used not only in the production of high-class bodies, but also for numerous castings in connection with the engine and transmission equipment. Another industry largely dependent upon aluminum is that of aeroplane manufacture. The present advanced stage of aviation would not have been attained had there not been available aluminum and its various alloys. The steel industry is perhaps the next largest consumer of metallic alluminum in the shape of small notch bar and granulated metal. Here, it is used as a deoxidizer, and our present well-known high-grade steels would be impossible without the addition of aluminum to the crucibles before pouring.

Considerable aluminum is being used in the production of light alloys of widely varied composition. A large percentage of the metal is used in the cooking utensil industry, where it has come to be the ranking metal, as it affords immunity from poisons, and is light and durable. In this use, alone, it has been, and will continue to be, a great benefit to mankind.

The development of aluminum castings has opened up a comparatively new field, whose limits are at present entirely unknown, since several large concerns are limiting their operations entirely to the production of aluminum castings. For this work, they are supplied with various sizes and shapes of notch bar.

The newest industry dependent on aluminum is that of aluminum die castings. This industry is still in its experimental stage, but rapid development is expected in the near future.

The uses of aluminum are almost innumerable. One of the most important is that of electrical conductors. Large quantities are used in wire and bus-bar. Another important use is in aluminum foil, which is very largely supplanting tin foil as a wrapper for materials affected by atmospheric moisture. This list might be continued indefinitely, but we have only to look around to appreciate that aluminum is next to steel in importance in our every-day life.

Continuous electrical energy throughout the entire 24 hours of each day, and for the full 365 days in the year, is absolutely essential for the production of aluminum, and the aluminum industry being one of the largest users of continuous electrical energy, could not have attained its present proportions without a reasonably cheap and thoroughly reliable supply of electricity, such as is found at Niagara Falls. A shortage of power for a small length of time is sufficient to freeze up the pots, resulting in their premature renewals at much expense in labor and time. A slight lowering of the amount of electrical energy will cause a chilling of the furnace, resulting in the decreased output and increased operating difficulties. This is apparent when one considers that the normal temperature of the bath in these furnaces is exceedingly high, and the range between freezing temperature and that of favorable operation is very slight.

ABRASIVES

The next industry to come to Niagara Falls because of cheap and reliable Niagara power was the Carborundum Company.

It is a far cry indeed from the early historic days when Edward Goodrich Acheson made carborundum in an electric furnace fashioned from a small iron bowl, such as plumbers use, to the present time when electric furnaces 50 feet long use 2000 horse-power constantly for 36 hours to complete a furnace run.

A Carborundum Furnace, Producing the Manufactured Abrasive Carborundum

Resistance-type furnace using 2000 horse-power; size of carbon conductor 500 square inches; area occupied by furnace, 560 square feet; temperature 4000 degrees Fahrenheit

The first carborundum sold for $440 a pound and its only market was in competition with diamond powder for gem polishing.

Acheson's experiments were carried on at Monongahela City, Pennsylvania. In order to obtain a steady supply of electric current an electric light company was organized, and the enterprise lost money steadily. Finally the company was using 135 horse-power of electricity and producing at the rate of 45 tons per year.

How often it happens that two movements, unknown to each other and widely separated, start in a feeble way, plod along slowly but with increasing impetus, until they seemingly just happen to meet at the exact moment when each needs the aid of the other!

Here and there over the country men of science were working in their laboratories directing their thoughts to the development of nature through electricity, while at Niagara another set of men were directing their thoughts to the development of electricity through nature.

Battery of Arc-light Furnace Producing the Abrasive Aloxite

Temperature 3000 *degrees Fahrenheit*

Just at the time when cheap electricity became a necessity to the field of chemistry, it became an accomplished fact at Niagara.

In 1894 the Carborundum Company made a long term contract to use and pay for 1000 electrical horse-power. This was eight times the amount of power used at Monongahela and meant twenty times the output.

Time has justified the faith of these men. Today the Carborundum Company plant uses 20,000 electrical horse-power and employs 2000 men.

Niagara electric furnace abrasives have revolutionized the business of grinding and polishing. The great metal working industries turning out thousands of agricultural implements, locomotives, cash registers, firearms, milling machinery, automobiles, printing presses, depend upon artificial grinding materials for that precision in grinding that makes possible the interchangeability of parts. Production-time and costs are cut, production is increased, the product is bettered, the earning power of labor is raised, by these abrasives.

It is no exaggeration to say that if the automobile manufacturer was forced to go back to the old grindstone and at the same time was deprived of high speed steels and aluminum which are likewise made possible by Niagara power, the plant and men which now produce 500 cars a day could only produce 100. And, the hundred would be twice as heavy and cost two or three times as much as the present car.

Truly, modern personal transportation, as embodied in the automobile of today, would not exist were it not for the electric furnace products made commercial by Niagara power.

FERRO-ALLOYS

Since the advent of Niagara power in 1895, a large industry has developed which furnishes to steel makers alloys of iron with some of the rarer metals, in order to introduce these metals into steel.

Such alloys are known as ferro-alloys, because they all contain iron (ferrum); some, however, contain more of the rare metal than iron. They originally were made in crucibles, cupolas, or blast furnaces, but now they are made almost entirely in electric furnaces.

Great economies in production are offered by the electric furnace in the manufacture of ferro-alloys over the older blast furnace and crucible methods. The high temperatures available in the electric furnace cut down slag losses, makes available a much higher percentage of the metal in the ore, and so offsets its relatively higher cost of operation.

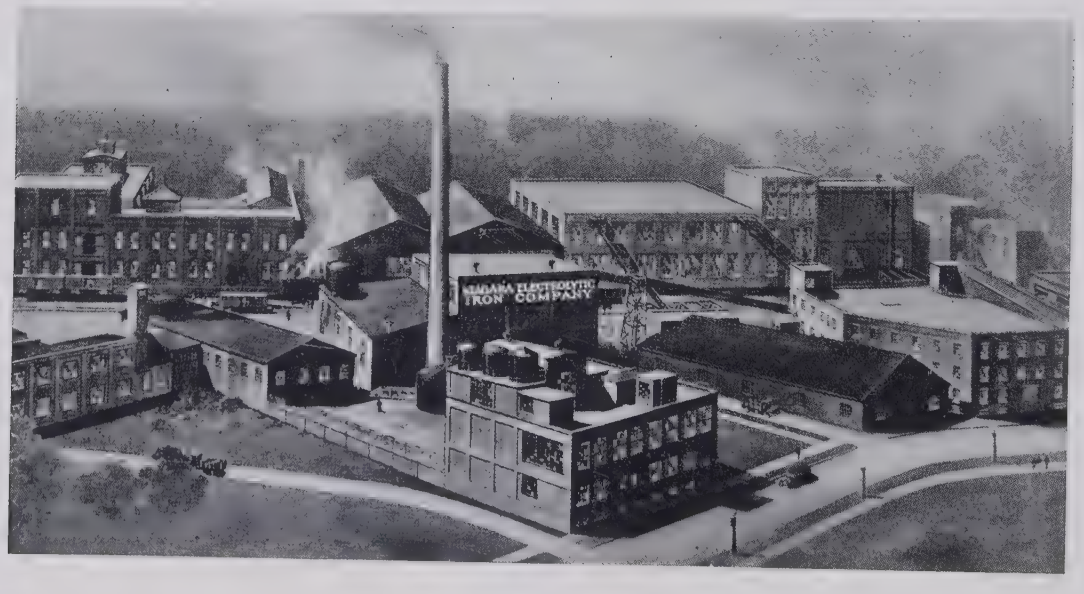
Steel makers use ferro-alloys for two purposes, mainly: (1) as reagents to take oxygen out of melted steel, and thus insure sound, solid castings; or. (2) to put into the steel a percentage of the rare metal to impart to the steel some characteristic which otherwise it would lack.

Ferrosilicon, ferromanganese and ferroaluminum are the principal reagents used for driving oxygen from molten steel. Oxygen, if not removed, causes cavities or blowholes in castings.

Ferromanganese is extensively used because of its relative cheapness; ferrosilicon is more effective but costs more than ferromanganese; ferroaluminum is even more powerful but still more costly and is usually employed in very small quantities to complete the action of silicon and manganese.

To point the practical application of the foregoing: by removing the oxygen from steel, it is possible to have an automobile axle about the size of a man's thumb but with the same strength as an axle twice the size made from ordinary carbon steel that has not been deoxidized.

The second great use of ferro-alloys is in the making of special steels with peculiar qualities not possessed by plain carbon steel. For example, the addition of 15 per cent manganese makes a very tough, hard steel from which to make burglar-proof vaults, mining, grinding and crushing machinery.



Niagara Electrolytic Iron Company, Incorporated
Niagara Falls, New York

Two to four per cent of chromium makes a very hard tool steel; 15 to 20 per cent of tungsten makes a high-speed tool steel which cuts very rapidly and which continues to cut even when red hot from friction. Molybdenum acts similarly to tungsten and is used for making steel for the lining of the big guns for the army and navy.

Vanadium adds a shock-resisting quality to steel and is used extensively in steel for automobile construction, especially for axles and crankshafts. Ford is said to have been the first American automobile manufacturer to use vanadium steel. It played a big part in his development of a light but strong vehicle.

Ferro-alloys made at Niagara Falls include:

Ferro Silicon	Ferro Tungsten
Ferro Chromium	Ferro Molybdenum
Ferro Carbon Titanium	

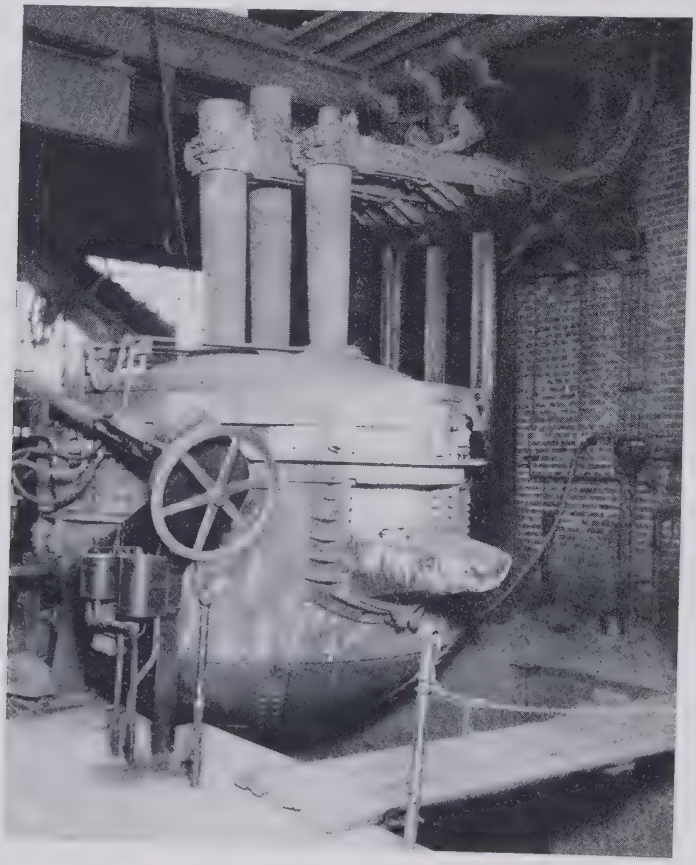
These products of Niagara electric furnaces are exceedingly important materials in all the industrial life of the world. They are practically indispensable to the steel industry as now constituted. In addition to the uses already mentioned ferro-alloys are absolutely essential to the production of modern shell steel, armor plate, projectiles, non-rusting steel, magnet steel, edged tools of all sorts, high-speed tool steel, electrical apparatus, modern typesetting and printing machinery, and hundreds of other articles of daily use in the factory, the office and the home.

Niagara Electrolytic Iron Company, Incorporated
Electrolytic Cell Assembly

SEAMLESS IRON TUBING MANUFACTURED

Probably the most important of the recent installations of electrometallurgical processes is that of the Niagara Electrolytic Iron Company.

This company is engaged in the manufacture of seamless tubing of pure iron, made by an electroplating process similar to that which has been in successful operation for several years at Grenoble, France. It is able by this method to produce thin-walled seamless tubing outside the range of ordinary tube-making processes, and which at the same time possesses an unusually high ductility and is relatively free from corrosion. These peculiar properties are due to the exceptional purity of the iron produced, which tests better than 99.95 per cent pure.



Electric Steel Melting Furnace. Otis Elevator Company,
Moore System. October, 1926

The process now in use employs pig iron and scrap iron as sources of raw material; however, the company has another process of manufacturing tubing directly from iron ore which it expects to put in operation a little later.

The company has a long term contract with The Niagara Falls Power Company for 6750 electrical horse-power. Its present installed capacity is

14,000 pounds of pure iron tubing per day, but the works have been designed for an ultimate output of 40,000 pounds per day.

HIGH-GRADE STEEL PRODUCTS

The electric steel melting furnace (Moore System) shown in the illustration on page 316 and used by the Otis Elevator Company is typical of several installations in and about Buffalo operated by Niagara power for the production of steel castings and other high-grade steel products.

The capacity of this furnace is three tons per heat requiring two-and-a-half hours per heat, or an average rate of production of one ton per hour, allowing for pouring and charging time.

The maximum energy demand is about 900 kilowatts normally. Fluctuating peaks run as high as 1200 kilowatts. The power consumption averages 550 kilowatts per ton.

The electrodes used are manufactured at Niagara Falls by the Acheson Graphite Company, are 10 inches in diameter and are consumed at the rate of about 4 pounds per ton of steel melted.

The material used in the production of steel, such as silicon, nickel, chrome and manganese are produced at Niagara Falls by Niagara power.

OTHER PRODUCTS

In addition to aluminum, abrasives and ferro-alloys, Niagara power is used extensively in the production of sodium, silicon, magnesium, potassium, phosphorus compounds, graphite and in the fixation of atmospheric nitrogen.

Silicon is used principally in the preparation of special alloys and in the generation of hydrogen. Silicon is produced from a charge of sand and coke in an arc-type electric furnace, requiring about 1200 electrical horse-power. High silicon steel is used in great quantity in the manufacture of electrical transformers.

Sodium is a metal with which the general public is little familiar. It is obtained by electrolysis of fused caustic soda, or fused common salt. This metal is light in color and relatively soft in substance. Its chief uses are in the manufacture of bearing metals, indigo and dyestuffs, in alloys, metallic cyanides, and sodium peroxide. Sodium cyanide is used for the extraction of gold and silver from ore of low grade, for electroplating, case-hardening, and for fumigation of trees, greenhouses, mills, ships and railway cars. Sodium peroxide is used for bleaching, in the generation of oxygen, and in the manufacture of hydrogen peroxide, and of other peroxides.

The science and application of electrolysis and electrothermics are so very extensive, and are evolving so rapidly, that it is impossible ever to have a complete up-to-date review of the subject. This is particularly so because many of the late developments are secrets which are most closely guarded. In this work, therefore, reference is made to only the more common processes and products. Free use is made of information gleaned from published works and articles in the technical press written by leaders of the electrochemical industry.

MAGNESIUM

The commercial manufacture of magnesium in the United States made little progress until the World War. Metallic magnesium had been isolated some years before the isolation of aluminum. The latter forged to the front ahead of magnesium for many reasons—alumina is more abundant and is more easily reduced to ingot form than is magnesium.

The process used in the production of commercial magnesium is based on electrolysis in a bath of fused salts. The raw material used is magnesium oxide obtained by the simple calcination of natural magnesium carbonate. Electrolytic decomposition of the oxide is carried on in a bath of fluorides. The process is continuous, and is similar to the oxide process so extensively used for the electrolytic production of aluminum.

Magnesium is lighter than aluminum. It can be alloyed with many other metals. At present it finds its greatest use in the manufacture of light-weight castings, light-weight alloys, for deoxidizing, for hardening of lead and anti-friction alloys, and in brasses and bronzes.

The first use of magnesium was for photographic flash-light powder. During the World War it was used in great volume in the making of tracer ammunition, for military and commercial pyrotechnic signals, and as a pigment for paint.

Magnesium is produced in ingots, sheets, plates, rods and other extruded forms for commercial use. It is also made in wire, ribbon, and powder for chemical applications.

The market for magnesium in volume is just being developed but there is no doubt it will displace other metals for many purposes where a light-weight yet strong metal is needed. It has already found its place as shuttles and bobbins for textile machinery; parts for knitting machines; lens mountings and camera parts; field glasses; parts for precision and surveying instruments; artificial limbs; golf club heads; dental tool handles; screw machine products; automobile and airplane parts; and as a substitute for horn in such articles as combs and buttons.

CALCIUM CARBIDE

In the manufacture of calcium carbide the materials used are lime and coke in an electric furnace of the arc type. The operation of these furnaces at

Niagara is continuous, and requires many thousands electrical horse-power per unit. There are single furnaces 30 feet square and 15 feet high which utilize 20,000 horse-power, and the electrodes which lead the current into the furnaces weigh several tons each.

Calcium carbide and the great industry that has developed through its manufacture owe their existence to an accidental discovery made in 1892 at an aluminum works in Spray, North Carolina. At that time an effort was being made to reduce lime by carbon in order to make calcium, which it was hoped would prove an aid in the reduction of aluminum. While these experiments were in progress, it was discovered that the carbide product gave off an inflammable gas when it came in contact with water. An analysis resulted in its recognition as calcium carbide, an article of great commercial value. Calcium carbide furnishes upwards of five cubic feet of acetylene gas per pound. This gas burns with a soft, steady, brilliant flame.

Acetylene gas is used in oxyacetylene cutting and welding operations, and for special illumination installations such as lighthouses, buoys, searchlights, signal lights, mining lamps, and for domestic illumination.

GRAPHITE

In the ordinary arc lamp used for street lighting the amount of electrical power which is converted into heat between the points of the carbons is only about one-half horse-power, and yet at that point in the incandescent vapors of the arc a temperature of about 7500 degrees Fahrenheit is maintained. Particles of sand, alumina or iron placed in the arc disappear almost instantly, like so much moisture.

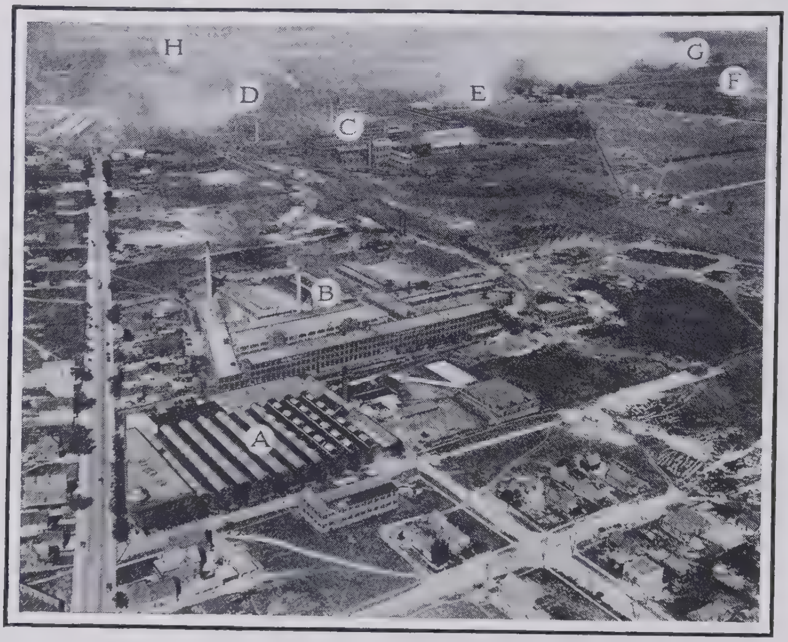
Examined through suitable magnifying glasses, the points of the two carbons look like the craters of miniature volcanoes, with the impurities of the carbon bubbling up over the surface and disappearing in the incandescent vapors of the arc.

This, on a small scale, is an electric furnace.

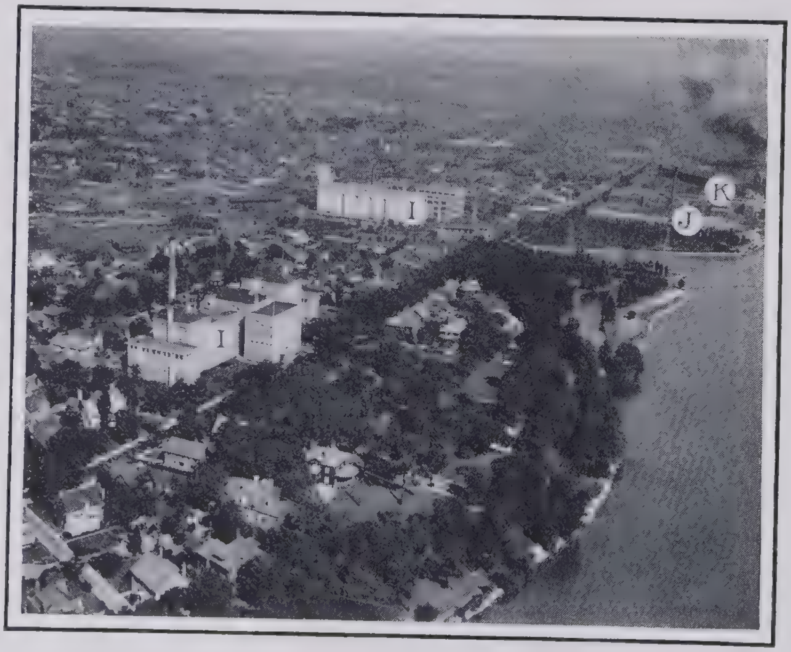
In the production of artificial graphite the furnace used is a long, narrow trough or box of refractory material, with a large terminal at either end, corresponding to the two carbons of the arc lamp. The material to be treated, which is some form of carbon, usually coke or anthracite coal, and is itself a conductor of electricity, is crushed to a granular form and loaded into this trough in the path of the current of electricity between the two carbon terminals.

Instead of a big arc, therefore, between the two terminals, the arc is broken up and subdivided by the intervening particles, and the charge is subjected to the heating action of an infinite number of smaller arcs, expending an

NIAGARA'S BASIC INDUSTRIES

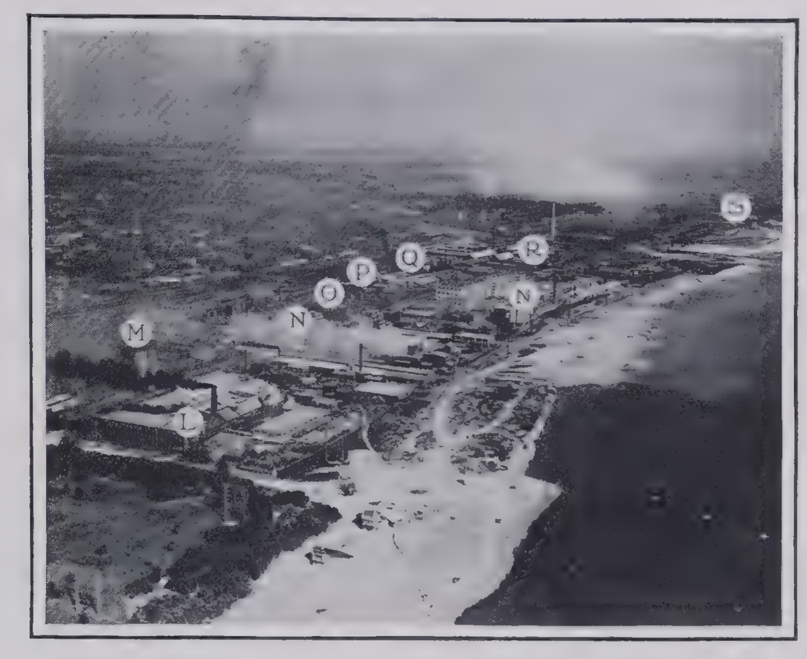


A *American Sales Book Company*
B *United States Light & Heat Corporation*
C *National Carbon Company, Incorporated*
D *Pittsburgh Metallurgical Company*
E *General Abrasive Company*
F *Republic Carbon Company, Incorporated*
G *United States Ferro Alloys Corporation*
H *Titanium Alloy Manufacturing Company*

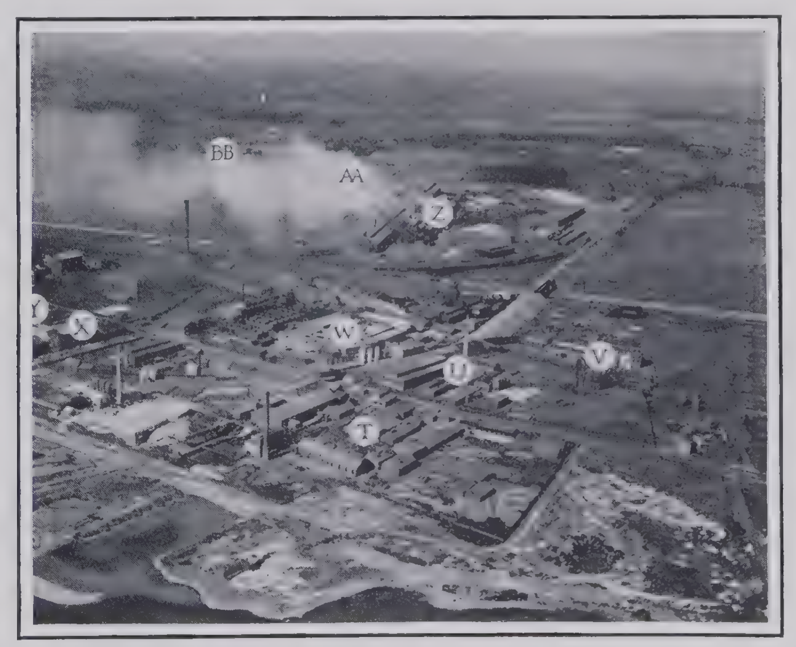


I *Shredded Wheat Company* J *Gilman Fanfold Corporation, Limited*
K *International Paper Company*

NIAGARA'S BASIC INDUSTRIES



L	*Certainteed Products Corporation*
M	*Acheson Graphite Company*
N	*Carborundum Company*
O	*American Magnesium Corporation*
P	*Mathieson Alkali Works, Incorporated*
Q	*Niagara Electro Chemical Company*
R	*Norton Company*
S	*Ramapo-Ajax Corporation*



T	*Oldbury Electro Chemical Company*
U	*Phosphorus Compound Company*
V	*Niagara Ammonia Company, Incorporated*
W	*Hooker Electro Chemical Company*
X	*Electro Bleaching Gas Company*
Y	*Niagara Alkali Company*
Z	*Union Carbide Company*
AA	*Isco Chemical Company*
BB	*Kimberly-Clark Company*

aggregate amount of energy of 2000 horse-power, or corresponding to the heat developed by 4000 arc lamps. The whole interior of the furnace becomes a mass of infinitesimal arcs and incandescent particles.

It is hard to conceive the temperature attained. Here all materials excepting carbon are vaporized, and at this high temperature even the carbon undergoes a change and forms pure graphite.

Many and varied are the uses to which artificial graphite is put. It occupies a great place in the field of lubrication. Crushed and separated to the most minute particles, it is mixed with water, and with oil and with grease to form the Dag Family of lubricants known as Aquadag, Oildag and Gredag. It is formed into electrodes for electric furnaces and for electrolytic cells; it is used for making dry cell batteries; for lead pencils; for stove polish; for gun powder; for hard rubber; for brushes; for resistances; and for a multitude of other uses.

CHLORINE

One of the largest users of Niagara power is the chlorine industry. This story of chlorine might be captioned "the romance of a grain of salt."

While there is some variation in the particular processes used by the different companies, in general the method of procedure is as follows:

A saturated solution of common salt is run into a series of electrolytic cells. In these cells a graphite electrode is surrounded by a large tube and the annular space between is filled with brine. The tube is surrounded by another or cathode tube. The current of electricity disintegrates the brine. Chlorine gas rises in the inner tube and is piped from the cell system. As it leaves the cells it is very moist and is carried through vitreous pipes to the liquefiers. These are a sort of pump which puts the gas under pressure when it takes the form of liquid chlorine. In this form it is put into steel cylinders and shipped over the world to be used for the purification of the drinking water supplies of the vast majority of cities and villages. Its use has brought about the practical elimination of typhoid fever in nearly all American communities.

Instead of being liquefied, the gas may be led to chambers containing slacked lime which absorbs the chlorine gas and forms bleaching powder.

Chlorine gas was the basis of poison gases used during the World War. It was also used in making cloud gas, smoke screens, disinfectants, sterilizers, explosives, picric acid, airplane waterproofing, chloroform, and a preventative of blood poison from infected wounds.

The liquid that remains in the cell is caustic soda. It is drawn off from the cell to multiple-effect vacuum pans or evaporators which remove the excess of water, reducing the caustic to a heavy liquid or to a solid.

So the ordinary table salt, passed through an electrolytic cell, goes out into the world to serve a great variety of needs. As liquid chlorine it is used in water purification, in textile bleaching, in paper and pulp bleaching, in sewage sterilization, in metallurgical processes, and in miscellaneous chemical manufacturing processes.

In the form of caustic soda, the transformed salt takes its part in soap making, paper making, glass making, in the manufacture of greases and lubricants, in oil refining, in the textile industry, and in countless other processes.

MISCELLANEOUS

Among the lesser products, lesser in volume but none the less important in their functions, are the following:

Fused alumina which is used as a refractory in high temperature furnaces, and for pyrometer tubes, crucibles, combustion boats, filtering devices, cements, cores and tubes in foundry work.

Silicon carbide is used as a refractory brick and muffle in electric furnace operations.

Sodium bichromate and potassium bichromate do their duty in the tanning of leather, as mordant in cotton dyeing, in the manufacture of dyestuffs as alizarine, in the preparation of dry chrome colors, in the manufacture of ferrochrome and as an oxidizer.

Among the great family of chemicals we also have chrome alum and chromium sulphate and chromic acid, all used in the leather industry for tanning purposes.

Then there is paraformaldehyde and trioxymethylene which are used as disinfectants, for dyestuffs, for phenolic resins and drugs.

Methyl alcohol serves as a solvent and in the manufacture of dyestuffs and formaldehyde. Methyl acetone is a solvent and paint remover.

Hydrochloric acid is used for pickling, cleaning and for chemical and laboratory processes.

Carbon tetrachloride is used as a fire extinguisher, as a solvent and as a cleaning compound.

Other important chemicals produced by Niagara electric power are:

Sulphur chloride for vulcanizing rubber and for poison gases.

Caustic potash in the making of special soaps, lubricants, synthetic dyestuffs, toilet and laundry preparations, and for wool scouring.

Phosphorus compounds for matches, for phosphor bronze, for medicinal chemicals and hypophosphites.

Potassium perchlorate for pyrotechnic signals and barium chlorate for the same purpose.

Electricity is also used for the hydrogenation of vegetable oils transforming them into forms for use as vegetable stearine.

Cyanamid is another product of the electric furnace process which has a large field of service. This process involves the fixation of atmospheric nitrogen in lime or other carrier. This product is then used as fertilizer and in the manufacture of sodium cyanide, aqua ammonia, nitric acid, and many other things.

The war which the fruit raisers have successfully waged against the insects and other orchard pests has been won by the use of these products of fixed atmospheric nitrogen.

NIAGARA POWER IN LOCAL AND IN WORLD-WIDE SERVICE

The division of the output of the power-plants of The Niagara Falls Power Company in kilowatt hours for a period of a year indicates that about one-half of the electricity generated goes into direct service over a large area of western and central New York State. The other one-half of the kilowatt hours produced serves the entire world through its utilization in the electrochemical and electrometallurgical industries which produce the many prime materials so essential to the continued progress of industry not only in the United States but throughout the world.

During the year 1926, 135,000 kilowatts were used constantly in general public service and about 30,000 kilowatts for miscellaneous public service in the State of New York; and the metals and alloys industries used about 120,000 kilowatts; chemicals about 45,000 kilowatts; abrasives about 20,000 kilowatts; electrodes about 15,000 kilowatts.

FROM MECHANICAL TO ELECTRICAL POWER

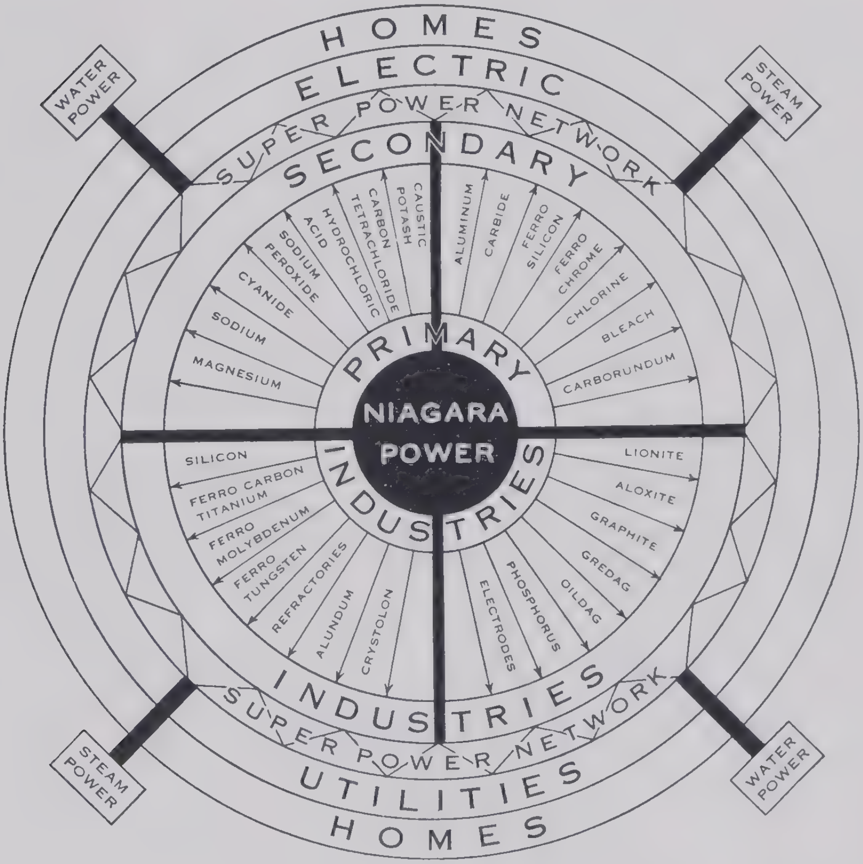
This review of the uses and the products of Niagara power reveals the great romance of recent scientific and engineering progress and presents the marvelous achievements which have quickly come from simple beginnings.

The ideal of the pioneers who proposed the hydraulic canal in the '40's and the discharge tunnel in the '80's, the projects which have developed into the present power system, was the water-wheel driving the mill—just like the sawmills and the grist-mills along the upper rapids a hundred and fifty years ago, only on a larger scale.

But the magic touch of electricity in a few short years transmuted the force of falling waters into a thousand wonders, performing service in a thousand ways.

These have been quickly incorporated into the fabric of our modern life; they are accepted as commonplace. Only a few score years ago they were beyond the dreams of the bold pioneers of Niagara, and the imagination of the Jules Vernes of those days, and they were then beyond the range of scientific and engineering achievement. But the engineering spirit which "views hopefully the hitherto unattainable" has brought a new world into being.

May we not reverently repeat the awe-inspired words which dedicated the first application of electricity to useful service, "What hath God wrought!"



Distribution of Niagara Power for Direct Service to Public Utilities and Homes and for Indirect Service for Primary Industries Which Supply Products for Secondary Industries Throughout the World

REVIEWS
AND REFLECTIONS

PUBLIC INTEREST IN NIAGARA POWER

Chapter XXVII

An Oriental Tribute to Niagara

此眞天下苐一江山

(This Is Really the World's Best River-Mountain)

PUBLIC INTEREST IN NIAGARA POWER

CHAPTER XXVII

VISITORS AT POWER-HOUSE

1895–1896

THE natural interest of the public in the scenery at Niagara was much increased during the period of 1879 to 1885, by the discussion, in the press throughout this country, regarding the injury to the beauty of the falls and the impairment of the opportunity to enjoy it, by the commercial encroachments upon its shore and islands. The establishment of the state reservation July 15, 1885, duly restored the natural condition of the scenery on the islands and on the river bank for a mile above the falls.

Another menace was thought to have arisen in 1890, continuing thereafter for several years, when the utilization of the falls was proposed as a source of power, upon a larger scale than theretofore undertaken, with the prospect of drawing an important amount of water away from the falls, thereby possibly injuring its majesty by diminishing its volume.

Special charters had been granted by the state under which such withdrawal of the waters of the upper river had been authorized without limit in amount.

A scientific commission in London had considered the best plans to utilize the power of a very large amount of this water, and its conferences again aroused public attention in the State of New York and its surrounding communities to the possible injury to its Great Falls. This led to further legislation restricting the amount of water to be withdrawn daily under the charter of 1886, to about 200,000 horse-power. This amount seemed alarmingly large to the public, and authoritative announcements by the state engineer that its probable effect of not exceeding 1½ inches upon the depth of the falling river would not be noticeable, and that so small a part of so great and rapidly moving a volume would be very difficult to measure even by the most skillful surveyors, failed to reassure the public, who wanted to judge of this themselves.

The reports from Europe that novel and enormous hydro-electric units were to be established at Niagara to transmit power to great distances, where it would supplant power formerly supplied by coal, aroused the æsthetes to protect their cherished and endangered scenic interests; while the engineers and manufacturers were attracted by the probable development for its own sake, and as an example of what might be accomplished elsewhere.

The visitors at Niagara Falls increased at the first evidence of active construction of the power-plant and probably reached a maximum number during the World's Columbian Exposition at Chicago, from which Niagara was found an interesting and restful sojourn.

As soon as Power-house Number One had been erected and its first turbogenerators were in operation in 1895, the number of visitors at the powerhouse greatly increased, and special attendants became necessary for their guidance and protection. The elevator in the wheel-pit was in frequent use, and the working models of the turbines and their governors were always the subject of much interest and questioning.

Visitors' books for registration of names and addresses were provided for distinguished guests, particularly those bringing letters of introduction from Europe and elsewhere. An examination of the volumes discloses that during several years at about that period the following countries were represented, several times in most cases:

Argentine
Austria
Belgium
Brazil
Bulgaria
Canada
Ceylon
China
Cuba
Egypt
England
France
Germany
Greece
Holland
Hungary
Iceland
India
Italy
Jamaica
Japan
Mexico
Norway
Philippines
Rhodesia
Roumania
Russia
Siam
Sweden
Switzerland
Venezuela

Thirty-one nations were represented and many states of North America. These visitors were known by their introductions, as representing organizations of engineers, state, church, army and navy. As a class, engineers were the most numerous. They came from all countries, particularly our own, and usually appeared well informed in a general way of the company's problems and how they were being solved.

Many societies of scientists and engineers came for the annual meetings of their members. Others attended stated conferences of national and international associations, such as the New York State Waterways Commission and the International Waterways Commission. The Imperial Chinese High Commission was represented by His Imperial Chinese Majesty's High Commissioner, Tuan Fang, Governor-General of Two Provinces, who signed his name with titles and added this expression of his appreciation, which literally translated means

> This is the real number one river landscape under heaven.

Among many other distinguished visitors with their official staffs were:

Prince Pu Lun, of China
Prince Henry, of Pless, Germany
Prince Michael Hilkoff, of Russia
Crown Prince of Belgium
Prince Kampangpetch, of Siam

Theodore Roosevelt, from the Executive Mansion at Albany, wrote:

> A marvel indeed!

Nikola Tesla, wrote under address:

> Stop in New York, but heart is at Niagara.

Jules Siegfried, Ministre du Commerce, Paris:

> Je serais heureux que nous puissions avoir en France un pareil éstablishment qui est une veritable merveille du temps moderne.

William Mather, Engineer, of England:

> This powerful plant is worthy of the falls and a monument to American engineering service and practise.

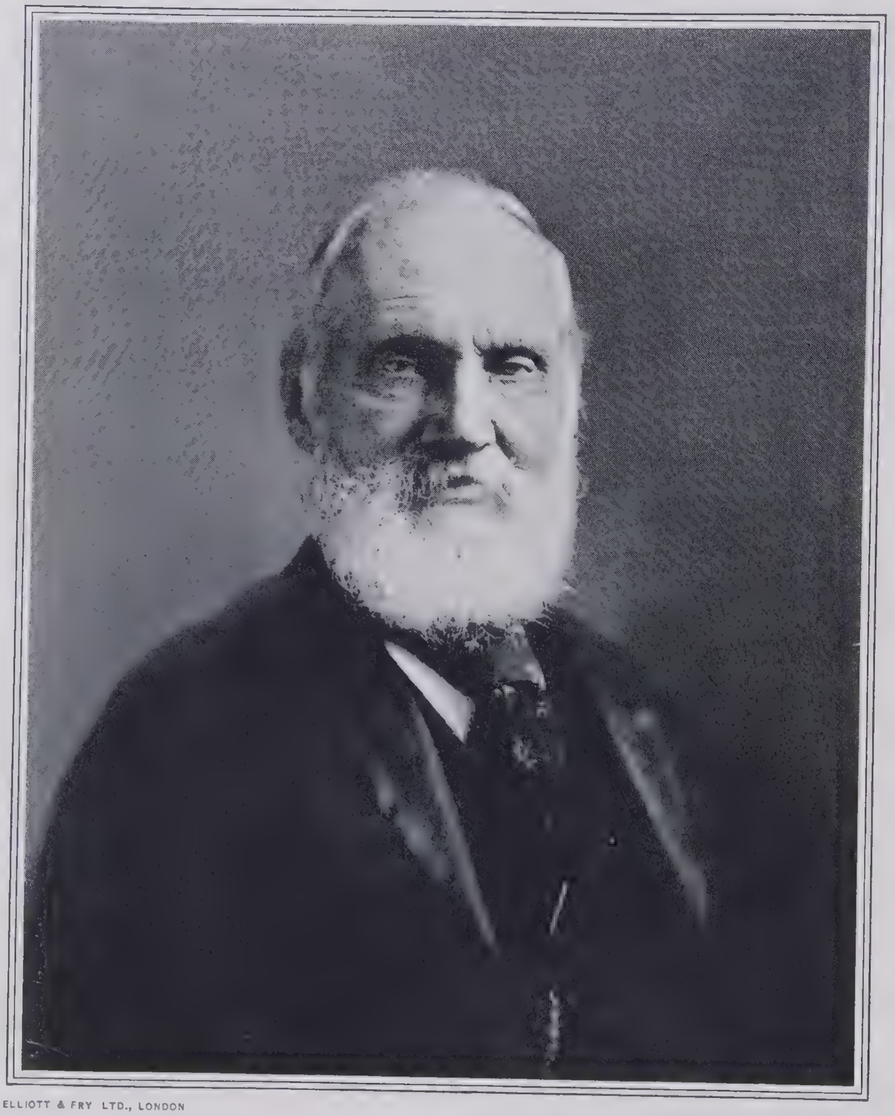
Henry S. Bovey, McGill University, Montreal, wrote:

> The members of Section G of the British Association desire me to record their deep appreciation of the kindness of Dr. Coleman Sellers during a visit to the power-house today (August 8, 1897), and to express their thanks for the explanation given by Dr. Sellers of the intricate machinery. They also desire to record their admiration of this magnificent undertaking.

LORD KELVIN AT NIAGARA IN 1897

Lord Kelvin of Largs, president of the Institution of Electrical Engineers of London, who had been the most influential and persistent adviser against the adoption of alternating current as president of the International Niagara Commission of 1891,[1] so openly declared his conversion to the company's faith when he visited the plant of The Niagara Falls Power Company in August, 1897, that he immediately commanded the highest admiration of all the Niagara adventurers.

[1] See Chapter X, Volume I.



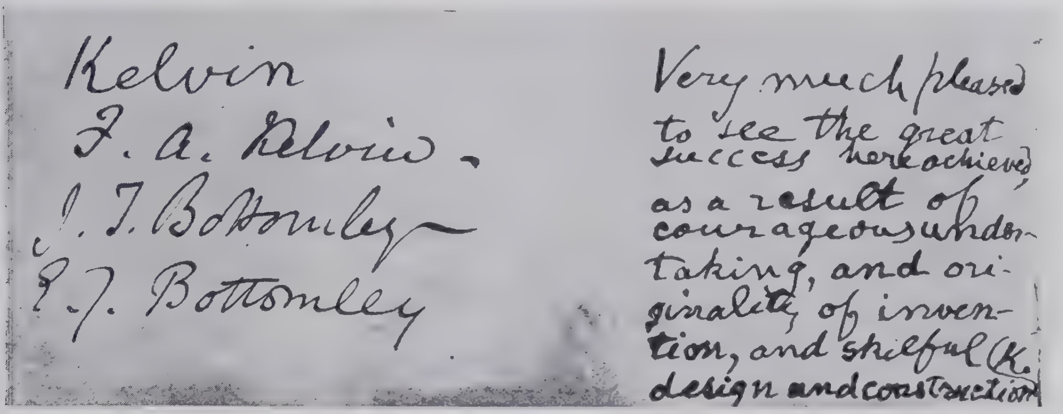
ELLIOTT & FRY LTD., LONDON

LORD KELVIN, F.R.S., PRES., 1890–1895, O.M., ETC.

President, INSTITUTION OF ELECTRICAL ENGINEERS
1874, 1889, 1907
(William Thomson)
1824–1907

The visitors' record book of Power-house Number One, preserves the signatures under August 16, 1897, of many scientists of international repute, members of the British association, among which are those of Lord Kelvin and his family, with this comment:

> Very much pleased to see the great success here achieved, as a result of courageous undertaking, and originality of invention, and skilful design and construction.



Kelvin
F. A. Kelvin
J. T. Bottomley
E. J. Bottomley

Very much pleased
to see the great
success here achieved
as a result of
courageous under-
taking, and ori-
ginality of inven-
tion, and skilful (K.
design and construction

Facsimile Signatures of Lord Kelvin and Lady Kelvin, Also Those of James Thomson Bottomley, D.Sc., F.R.S., Electrical Engineer, Nephew of Lord Kelvin, and Eliza Jennet Bottomley, Wife of Dr. Bottomley

He wrote from Toronto, August 23, 1897, after his visit to Niagara, as follows:

> I was greatly pleased with all the engineering, both hydraulic and electric, which I saw in the power-house, and in the distribution of the power to the factories in the neighborhood and to the trolley lines and most particularly to Buffalo for the distant section of the line between Buffalo and Niagara. The results thoroughly justified Dr. Coleman Sellers in his adoption of the alternate-current system at a time when the promise of good results from it on a large scale was only beginning to come from the tentative work of a much smaller character.

After visiting George Westinghouse in the autumn of that year, 1897, he wrote a letter in which he stated that since his visit to America and his talk with Mr. Westinghouse he had become thoroughly convinced that the polyphase transmission scheme was practicable, and that he would recommend it rather than the direct-current scheme he originally advocated.

STUDENT VISITORS

From time to time special attention was given to numerous visitations, by professors of engineering with their students from different colleges.

In 1900, after the two American power-houses had been in full operation, The Niagara Falls Power Company was obliged to post the following notice:

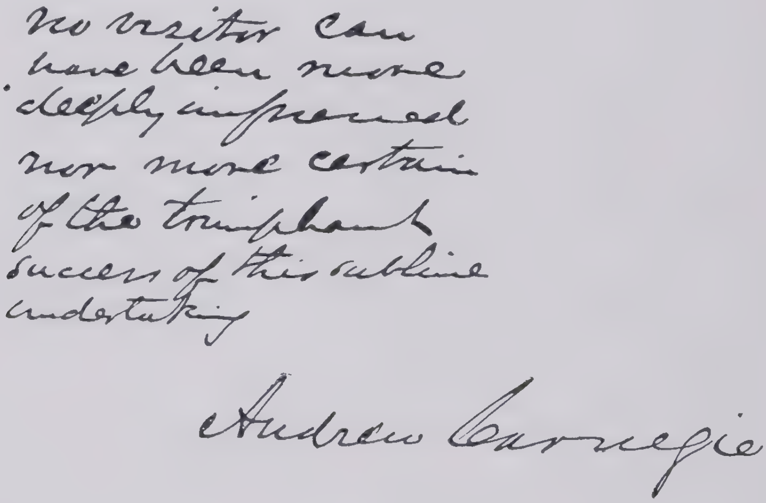
GUIDES

The requests for permission to inspect the plant of The Niagara Falls Power Company are so numerous that it is impossible for the officers of the company to give individual attention to such requests. The company desires however, to afford its visitors every reasonable facility for the gratification of the interest that is taken in its works, and to this end has provided competent guides for the purpose of conducting visitors through the establishment.

To defray the cost of the guides and door-keeper a small admission fee[1] is charged. From the admission receipts, after paying expenses, a bed in the Niagara Falls Memorial Hospital has been endowed for the use of employees who may be disabled by sickness or accident. From these receipts, appropriations are made also for the purposes of the hospital, of the Employees' Beneficial Association, and for the benefit of the employees in other ways.

In fourteen years these fees had amounted to $46,441, and the total amount was currently expended for hospital and helpful service for the employees.

The following facsimile signatures of a few of the early visitors (in the years 1895 to 1904) will illustrate the interest of scientists and many distinguished foreigners in the great engineering works at Niagara.



no visitor can
have been more
deeply impressed
nor more certain
of the triumphant
success of this sublime
undertaking

Andrew Carnegie

---

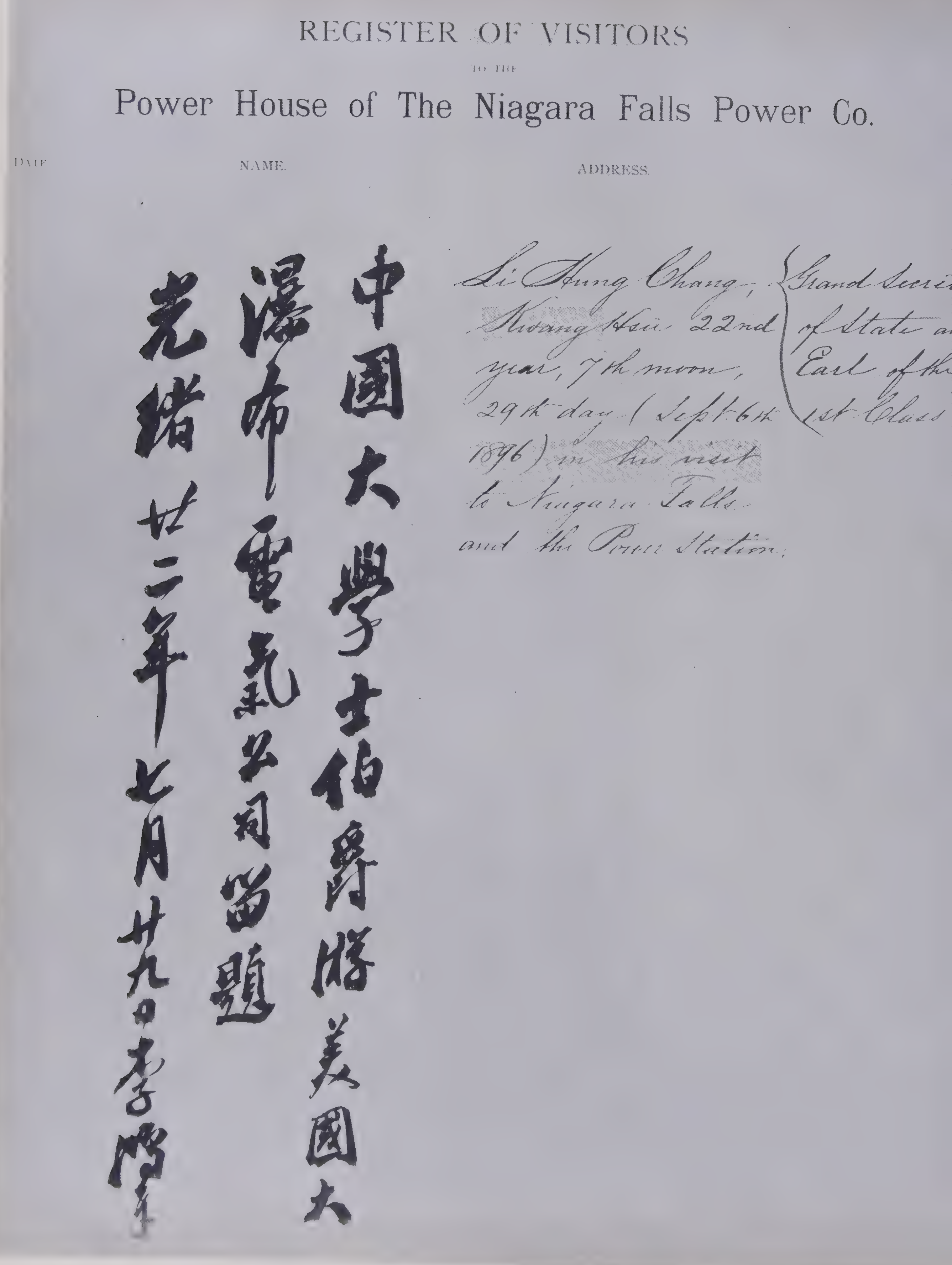
[1] Since 1918 the power-plants of The Niagara Falls Power Company have been open to inspection by the public, and guides have been provided without charge to visitors. During 1926, more than 100,000 visited the main generating station.

REGISTER OF VISITORS

TO THE

Power House of The Niagara Falls Power Co.

E	NAME	ADDRESS.
95 pt. 5th	Edward D. Adams	New York
"	J. J. Astor	" "
"	T. S. Bowdoin	New York
"	Charles Lanier	do
"	D. O. Mills	do
"	Wm. B. Rankine	do
"	Francis Lynde Stetson	do
"	Edward A. Wickes	do
"	John Crosby Brown	do
"	F. K. Sturgis	New york
t 24th	J. Pierpont Morgan	do
"	Wm. Croswell Doane	Albany
"	Henry C. Potter	New York
"	James J. Goodwin	Hartford
"	Sarah Katharine Doane	Albany
"	Frances L. Morgan	New York
"	Amy C. Townsend	New-York
31st	Coleman Sellers	Philadelphia Pa
"	W. A. Brackenridge	Niagara Falls N.Y.
	[illegible]	do
	Lauren W. Pettebone	do
	Robert A. Porter	"
	Jno. S. Hemmworth	"



REGISTER OF VISITORS

TO THE

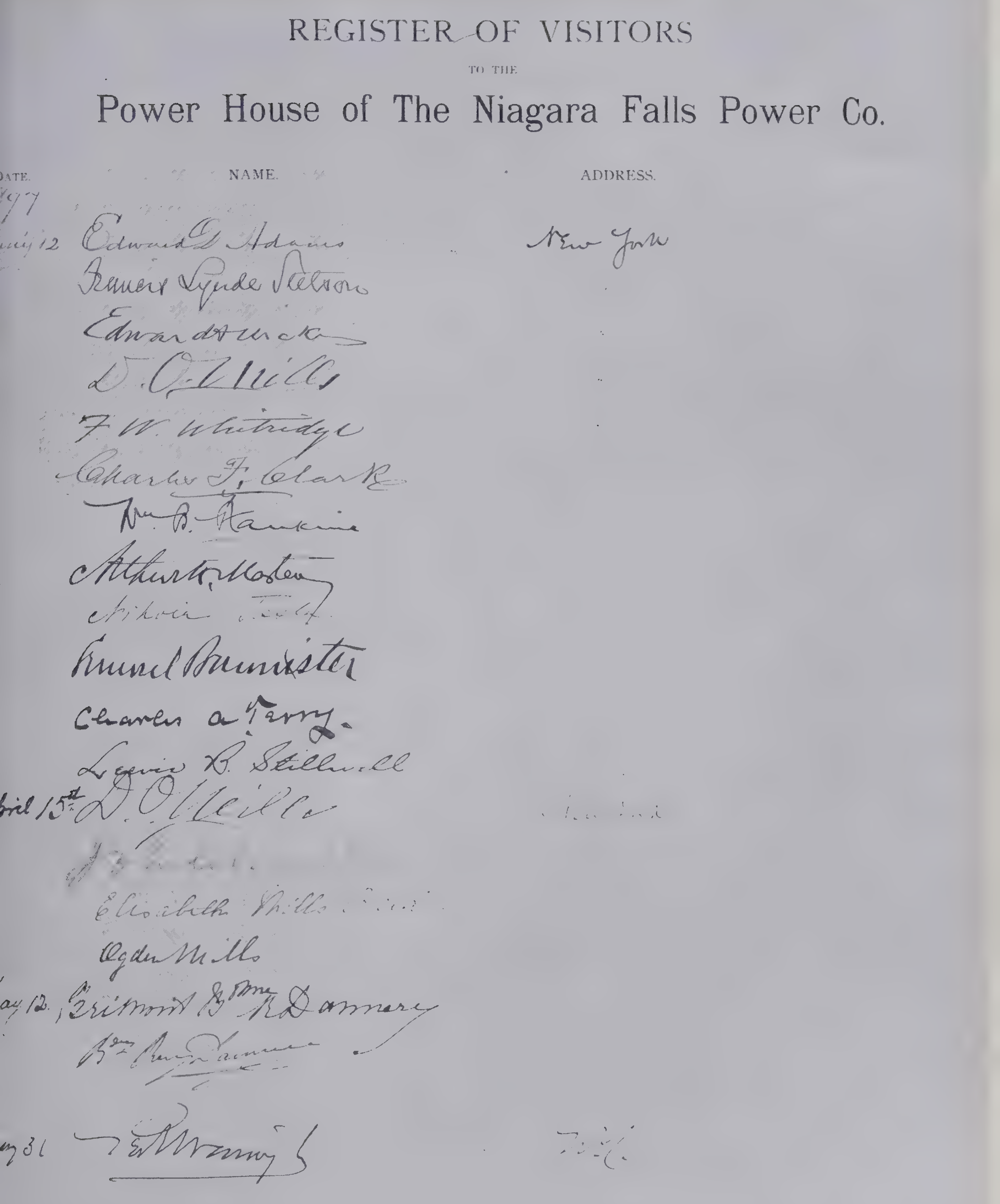
Power House of The Niagara Falls Power Co.

DATE NAME. ADDRESS.

中國大學士伯爵游美國大瀑布電氣公司留題
光緒廿二年七月廿九日李鴻章

Li Hung Chang, Kwang Hsü 22nd year, 7th moon, 29th day (Sept. 6th 1896) in his visit to Niagara Falls and the Power Station.

Grand Secre
of State a
Earl of th
1st Class

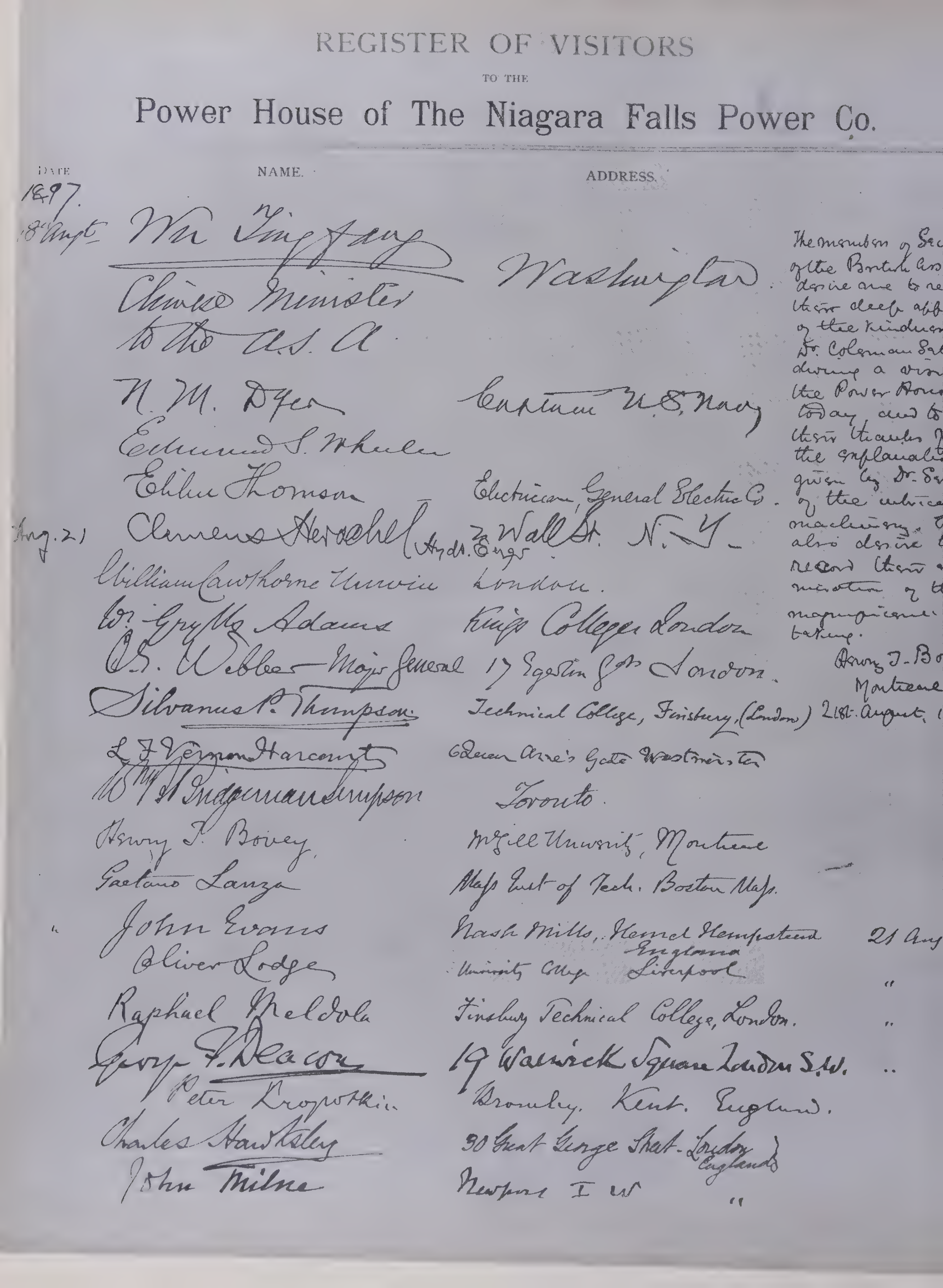


REGISTER OF VISITORS

TO THE

Power House of The Niagara Falls Power Co.

DATE.	NAME.	ADDRESS.
97		
12	Edward D. Adams	New York
	Francis Lynde Stetson	
	Edward A. Wickes	
	D. O. Mills	
	F. W. Whitridge	
	Charles F. Clark	
	Wm. B. Rankine	
	Arthur K. Masten	
	[illegible]	
	Kunnel Burmister	
	Charles A. Terry	
	Lewis B. Stillwell	
ril 15th	D. O. Mills	[illegible]
	[illegible]	
	Elisabeth Mills Reid	
	Ogden Mills	
ay 12.	[illegible]	
	[illegible]	
y 31	[illegible]	[illegible]



REGISTER OF VISITORS

TO THE

Power House of The Niagara Falls Power Co.

DATE	NAME.	ADDRESS.	
1897.			
18th Augt.	Wu Tingfang Chinese Minister to the U.S.A	Washington	
	N. M. Dyer	Captain U.S. Navy	
	Edmund S. Wheeler		
	Elihu Thomson	Electrician, General Electric Co.	
Aug. 21	Clemens Herschel (Hydr. Engr	2 Wall St. N. Y.	
	William Cawthorne Unwin	London.	
	Wm. Grylls Adams	Kings College London	
	C. E. Webber Major General	17 Egerton Gds London.	
	Silvanus P. Thompson	Technical College, Finsbury, (London)	21st. August, (
	L. F. Vernon Harcourt	6 Queen Anne's Gate Westminster	
	Wm H Bridgeman Simpson	Toronto.	
	Henry T. Bovey.	McGill University, Montreal	
	Gaetano Lanza	Mass Inst of Tech. Boston Mass.	
〃	John Evans	Nash Mills, Hemel Hempstead England	21 Aug
	Oliver Lodge	University College Liverpool	〃
	Raphael Meldola	Finsbury Technical College, London.	〃
	George F. Deacon	19 Warwick Square London S.W.	〃
	Peter Kropotkin	Bromley. Kent. England.	
	Charles Hawksley	30 Great George Street London England	
	John Milne	Newport I W 〃	

The members of Sec
of the British As
desire me to re
their deep app
of the kindness
Dr. Coleman Sel
during a visi
the Power Hous
today, and to
their thanks f
the explanati
given by Dr. Se
of the electric
machinery. T
also desire t
record their a
miration of th
magnificent
taking.

Henry T. Bo
Montreal

DATE.	NAME.	ADDRESS.
v. 4 1902	วชิราวุธ Maha Vajiravudh	Crown Prince of Siam and party
	[illegible] Akharaj Varadharer.	
	[illegible] Rajavallabh	
	หลวงสรสิทธิ์ Sarasiddhi	
	หม่อมอนุวัตรวรพงษ์ Anuvatra	
	Edward H Loftus [illegible]	
	J. H. Gore	
22	[illegible]	London
	Henry J. Pierce	Buffalo.
	Sir Albert K. Rollit M.P.	45 Belgrave Square London
	Sir Vincent Barrington	57 Albert Hall Mansions London.
	J. T. Wood	London
	Arthur Serena	do
	Kenric B. Murray	"
	F. Faithfull Begg	do
	[illegible]	London
29/04	大清國貝勒溥倫 Prince Pu Lun	
	黃開甲 Wong Kai Kah	
	[illegible] Francis Lynde Stetson Wm. B. Rankine	Original Incorporators Cataract Construction Company 13 June 1889
	Forsyth Wickes	New York
4	Edw. Mallinckrodt	St. Louis

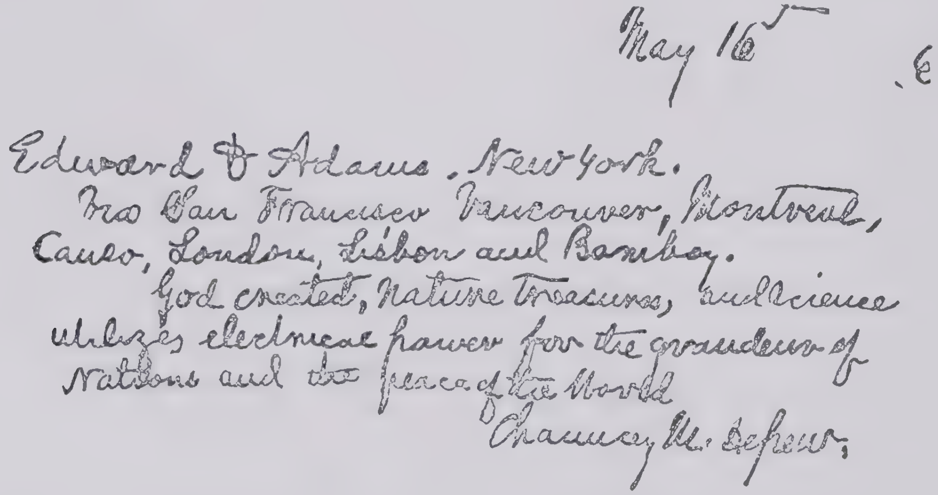
NIAGARA HARNESSED—A WORLD MESSAGE, 1896

Availing of a favorable opportunity to announce to the civilized world the successful harnessing of Niagara, and to commemorate the influence of Niagara in quickening hydro-electric activities around the globe, Hon. Chauncey M. Depew addressed the National Electrical Exposition in New York, May 16, 1896, on the subject of, "The Progress and Future of Electricity," and exchanged greetings with the president of The Cataract Construction Company by world transmissions.

While the messages were passing, one about 27,500 miles in fifty minutes, and the other, 18,000 miles in twenty-one minutes, Mr. Depew entertained his large audience by remarks which included the following statement:

> The imagination is paralyzed and the mind appalled in contemplating the endless centuries during which the boundless treasures God and nature had stored for the uses of mankind were left undiscovered and unknown. It was reserved for the nineteenth century, and for the second half of it, to wrest from the earth, the water and the air the potential and elemental powers which have rescued and regenerated the world.
>
> The familiars and the masters who have most beneficently yoked this mysterious power to the car of human progress are Franklin and Morse and Edison and Bell and Tesla and Brush and Westinghouse. The scientists of Europe have contributed many and invaluable discoveries to the development of electricity, but in its practical application and utilization for the common purposes of life and the grander march of civilization, America takes the lead.

Thomas A. Edison was at the telegraph key and received the messages here reproduced:

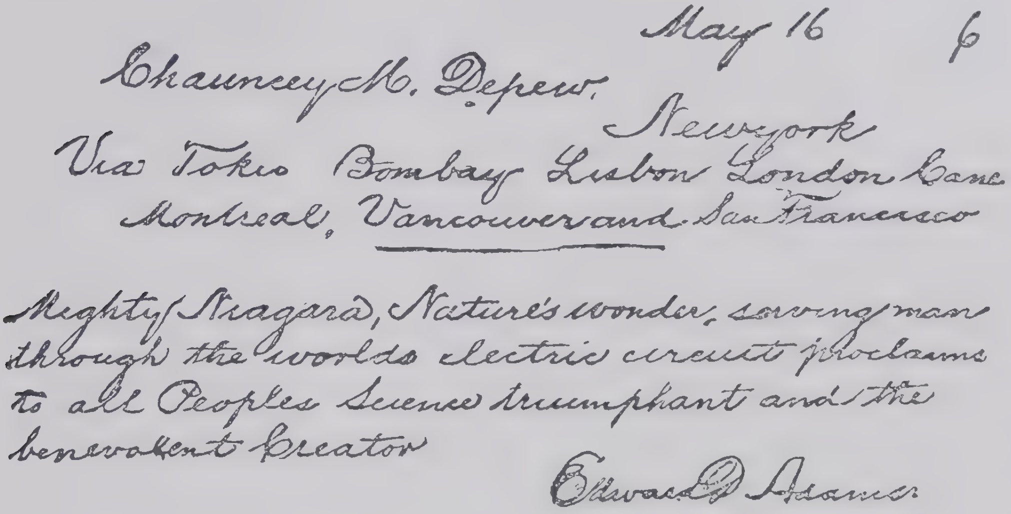


May 16th .6

Edward D Adams, New York.
Via San Francisco Vancouver, Montreal,
Canso, London, Lisbon and Bombay.
God created, nature treasures, and science
utilizes electrical power for the grandeur of
Nations and the peace of the world
Chauncey M. Depew.

Facsimile of Message from Chauncey M. Depew to Edward D. Adams—
To Tokio and Return in Fifty Minutes

The response of Mr. Adams was promptly sent from the following facsimile message:



May 16 6

Chauncey M. Depew.
Newyork
Via Tokio Bombay Lisbon London Canc
Montreal, Vancouver and San Francisco

Mighty Niagara, Nature's wonder, serving man through the worlds electric circuit proclaims to all Peoples Science triumphant and the benevolent Creator

Edward D Adams

Facsimile of Message from Edward D. Adams to Chauncey M. Depew—
To Tokio and Return in Fifty-six Minutes

This demonstration recalls the great event of May 24, 1844, when Prof. Samuel F. B. Morse sent in his sign alphabet, the first message by land line wire over the 40 miles, between Baltimore and Washington,

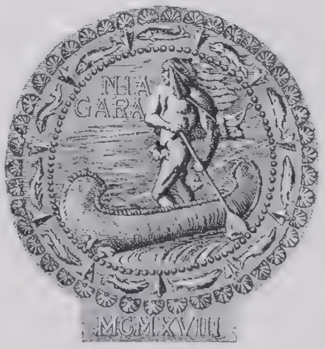
"What hath God wrought!"

THE NIAGARA SEAL, 1896

Seals from time immemorial have represented a means of assuring authority and secrecy.

In early history, they were made of clay, and later of wax and metals and semi-precious stones; they were ornamented by the sculptor and the engraver; they depicted the command, the generosity and the law of power and wealth; they were made important in size, variant in color, and impressive and significant in design.

The more artistic the seals, the more carefully were they preserved, with their important dates, portraits, names, titles and records of heroism and history.



In later years, seals have become emblems and are often used in assertion of militant, secular, heraldic and ecclesiastical power; as expressions of mottoes, legends, pride and personal taste; of union in action; of corporate authority; assurance of reliability and indications of influence and industry.

Sculptors are remembered by the greatness of their creations but none the less permanently by the skill of composition and execution of their coins, medals and seals. An artistic seal to be appropriate should perpetuate people in their conflicts and conquests and the beauty and grandeur of nature. A seal on a power-house is an innovation.

The seal was the crowning touch to the architectural setting of the Niagara power-house which distinguished it from former power-houses and gave a new significance to Niagara power. The part of the ordinary mill which housed its water-wheels, or the typical city electric plant of the early nineties alongside of railroad tracks and amid piles of coal and ashes gave no suggestion of architecture or seals.

The Niagara seal represents in a high degree the wonder of nature and the art of man; the romance of a dying race and the science of a new century.

This seal was formally adopted by all of the Niagara power companies, as will be seen by the following statements.

The By-laws of The Niagara Falls Power Company (consolidated 1918) Article 1, Section 1, read:

> The corporate seal of this corporation shall be the "MacMonnies design," heretofore used by The Niagara Falls Power Company, incorporated March 31, 1886, with the addition of the year of organization through consolidation of this corporation expressed in Roman letters (MCMXVIII) beneath the same.

At a meeting of the directors of the Niagara company of 1896, the following was recorded:

> A new corporate seal from a design of Frederick MacMonnies, presented by Mr. Edward D. Adams, was submitted to the directors and on motion of Mr. A. J. Porter, duly seconded, the same as impressed on this sheet was accepted and adopted as the corporate seal of this company, and the secretary was instructed to tender the thanks of the company to Mr. Adams.

The same seal was adopted by each of the affiliated or filial companies, with the addition thereto of designating words beneath the seal, to indicate the company executing the document to which the seal might be affixed. The filial companies of The Niagara Falls Power Company were as follows:

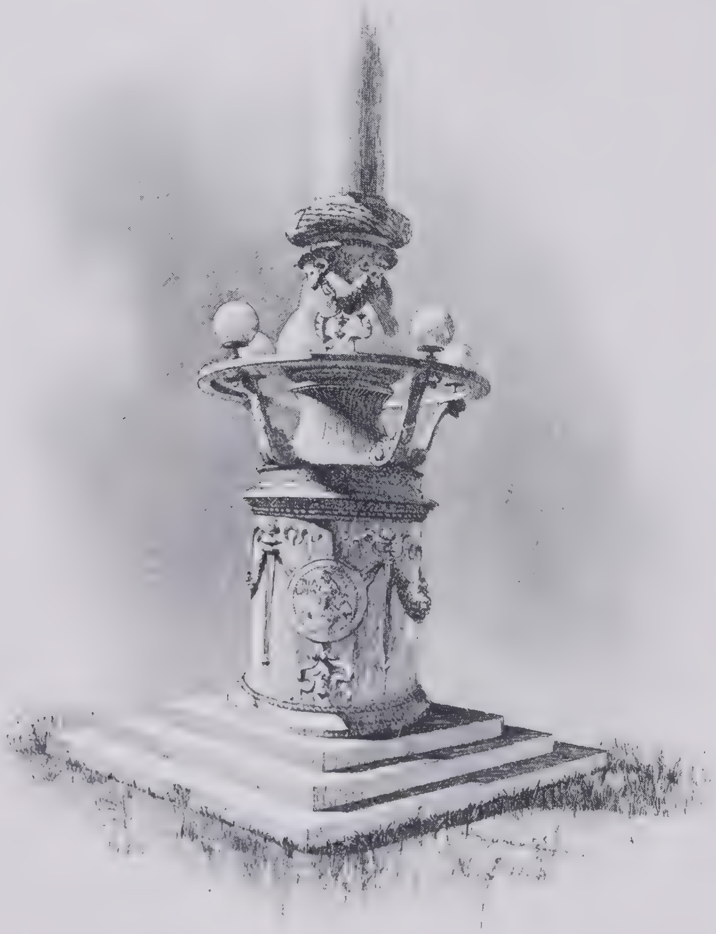
The Cataract Construction Company
Canadian Niagara Power Company
Niagara Junction Railway Company
Niagara Development Company
Cataract Power and Conduit Company

Each company used the design of the seal as its emblem at the upper left-hand corner of its engraved official stationery, a different color being used by each company to facilitate identification of its documents. It also appears on all engraved certificates of stocks and bonds of the several companies.

The Niagara seal is carved in a single stone of granite over the archway of the entrance to the main power-house and office building, in both the United States and Canada, and electrolytic reproductions were used to ornament the base of the flagpole at the entrance to Power-house Number One.

The Niagara seal was modelled by Frederick MacMonnies, the distinguished American sculptor, at his studio in Paris in 1895. The steel die was executed by Paulin Tasset, of Paris, the engraver of French and other governments' coins and medals.

Upon completion of the construction and the inauguration of the company's commercial work, the original steel cutting was returned to the donor, who uses it as a paper weight on his office desk.



Flag-pole Base in Front of the Entrance to Power-house Number One[1] and the General Offices of the Cataract and Niagara Companies, in the Middle of the Grass Circle of the Fore-court

The design of the seal may be described as follows:

The outline is a distorted circle, the metal being slightly pressed out of the regular circle form, in imitation of an early Greek coin struck without the use of a collar.

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[1] Designed by McKim, Mead and White, architects of power-houses of The Niagara Falls Power Company.

The central figure of an Indian chief in his canoe, floating down the rapids, seems an appropriate design for Niagara Falls and is correctly carried out in costume and other features. The chief is supposed to be named Ni-a-ga′-ra, and for the purpose of indicating the pronunciation, which is in four syllables with the accent on the third syllable, the word was divided with "Nia" on the top line and the "g" carried into the lower line, which, when held horizontally, shows the proper position of the canoe to indicate its rapid movement on the current of the rapids.

The water on the paddle blade rises in front of the paddle, with a slight depression, or eddy, behind it, indicating that the Indian is not trying to propel his canoe forward, but on the contrary, is pressing the paddle forward so as to restrain the speed of the canoe in the rapid current. The hands also indicate that this is the action.

The two decorative border lines are composed as follows: The fish represents the maskinonge (Esox nobilior) which is adopted in the design as indicating the king fish of that locality. The fish ornament is alternated with the design of an arrow-head, the native industry on land now owned by the company. The outer circle of ornament represents the Delthyris niagarensis, the typical fossil shell of the Niagara group of rocks.

A copy of this design as a medal has been acquired by the French government and is on exhibit in the Musée du Luxembourg at Paris. Copies appropriately inscribed were presented to each of the engineers who formed the board of engineers in the construction period of the work, and at about the same time a similar medal was presented to each director of the company. An example was deposited in the collection of medals belonging to each of the following institutions:

Metropolitan Museum of Art, New York
American Numismatic and Archaeological Society, New York
Museum of Fine Arts, Boston
Art Institute of Chicago
Buffalo Historical Society, Buffalo
Niagara Historical Society of Niagara Falls

REVIEWS
BY
ENGINEERS FORMERLY ENGAGED IN THE CONSTRUCTION AND OPERATION OF THE HYDRO-ELECTRIC PLANTS OF THE NIAGARA FALLS POWER COMPANY

Lewis B. Stillwell[1]
Harold Winthrop Buck
Paul M. Lincoln
George Forbes
William Cawthorne Unwin
Clemens Herschel

[1] See Appendix A, Volume I

Chapter XXVIII

REVIEWS
BY
ENGINEERS FORMERLY ENGAGED IN THE CONSTRUCTION AND OPERATION OF THE HYDRO-ELECTRIC PLANTS OF THE NIAGARA FALLS POWER COMPANY

CHAPTER XXVIII

IN an enterprise so epoch making and of such magnitude as that of The Niagara Falls Power Company, many engineers were employed. The daring nature of the work and its appeal to the imagination of the expert and layman alike attracted men to it. Although the status of the civil, mechanical and hydraulic engineer was then firmly established, electrical engineering as a profession was still very new.

Some of the engineers connected with the hydro-electric development at Niagara Falls were eminent in their respective professions at the time, while others achieved greatness either in connection with or subsequent to their association with the undertaking. A few of them have been kind enough to place on record for this volume some of their recollections of those early days with an estimate of the value of the work not only to engineering, but to posterity.

During the years which have elapsed since the Niagara development was first started and since these engineers have severed their connections with the enterprise, they have had ample opportunity for retrospect and judgment. Obviously, their judgments are tinged and hallowed by associations. Others perhaps less familiar with the details of the work but capable of beholding it with eyes undimmed by emotion and of judging it with minds unclouded by prejudice or passion, may some day evaluate its true worth. A sense of loyalty and duty has prompted these former associates in the Niagara enterprise to set down while memory is still clear and events are fresh, what they know of that development; for

> Not gold, but only men
> Can make a people great and strong;
> Brave men, who for truth and honor's sake,
> Stand fast and suffer long;
> Brave men who work while others sleep,
> Who dare, when others fly;
> These build the nation's temple deep
> And lift its pillars to the sky.

Harold Winthrop Buck
PRES. A. I. E. E., 1916–1917
Electrical Engineer of The Niagara
Falls Power Company and Its
Allied Companies
1900–1907

Harold Winthrop Buck makes the following statement of his views concerning the influences of power development at Niagara Falls:

The development of the Niagara Falls power system was unquestionably a great contribution to electrical engineering and all of the many modern hydro-electric systems can be traced back directly to the development at Niagara which served as the necessary precedent.

The adoption at Niagara of a frequency of 25 cycles, at a time when the standard alternating current was 133 cycles, was a very bold step in engineering and a very wise one. Another very bold step taken by the Niagara company was the adoption of very large generating units and the definite establishment of polyphase alternating current as the method of electrical power transmission, which has been standard throughout the country since that time.

At the time of adoption by Canadian Niagara Power Company of units of 10,000 horse-power they were the largest in capacity which had ever been successfully installed and the generating voltage of 12,000 volts was higher than anything established at the time. This size of unit and the generating voltage were determined upon the initiative of the power company.

Another matter in which the Niagara enterprise was a pioneer was in the large scale distribution of power by underground cables. In Buffalo it further led the way in establishing underground transmission at the voltage of 11,000 volts, which at the time was far in excess of anything which had been accomplished before.

The underground system of the Cataract Power and Conduit Company, in Buffalo, has been copied in most of the large cities in this country during the last twenty years.

During my administration of the electrical engineering department several propositions came before the power company for the transmission of large blocks of power to such places as Detroit, Cleveland and Pittsburgh.

The maximum voltage then in commercial use on transmission lines was 60,000 volts which was not high enough to solve the problem which the company had under consideration. A series of investigations was then undertaken under my direction for the purpose of developing ways and means for large scale power transmission.

Elaborate tests of wind pressure on long aerial conductor spans were made and a formula derived which has since been used extensively in transmission line calculations. An experimental transmission line was built one mile in length and various insulators of the pin type then available were given tests under service conditions in all kinds of weather at voltages up to 100,000 volts. It soon became evident that insulators of the pin type were not adequate for transmission at voltages in excess of 60,000 volts, and other means for line insulation were sought.

From these investigations there was developed and introduced the then radically new suspension type of line insulation,[1] which solved the high voltage problem and which has since become the standard system of high tension insulation throughout the world.

The history of the Niagara power enterprise here related shows clearly the great labor and difficulty involved in the building up of this great water-power development. Years of complex effort, great enterprise and originality and vast sums of money have all been necessary to final success.

The falling water supplied by nature is only one of the many elements which must be co-ordinated in order to bring to conclusion the complete operating hydro-electric system.

New York, 1926.

H. W. Buck

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[1] Chapter XXV, pages 280–283, Volume II.

Prof. Paul M. Lincoln
FEL. AND PAST-PRES. A.I.E.E., MEM. A.S.M.E.
MEM. A.E.S.

Prof. Paul M. Lincoln, of the electrical construction staff at Niagara in 1895–1902, past-president American Institute of Electrical Engineering, and director of electrical engineering at Cornell University, wrote in 1921:

> It is interesting to recall that the original Niagara plant was the first occasion where electric power was generated and distributed in large quantities. The foresight which dictated the choice of system in this case was remarkable, and I think it might be well to dwell on this point in any historical review of the matter. At the time the Niagara plant was projected, the use of polyphase alternating currents was practically unknown, and the impetus which the success of this system at Niagara gave to polyphase alternating current system is, I believe, to a very large degree responsible for the very rapid growth of that method of generation and distribution of power.
>
> It is only fitting and proper to recall, however, that the alternating current polyphase system of generating, transmitting and distributing energy did not, forthwith

upon its selection for Niagara, develop into the finished system that is so widely used today. In developing from the crudity of 1895 to the finished product of today there were birth pains a plenty. It was only natural that the first large system should be the one in which the most notable advances were made. Many of the notable advances of the art were first conceived for, and first used in connection with, the Niagara plant. The oil circuit-breaker, the porcelain high voltage insulator, mica insulation for generators, suitable methods for bracing generator windings against short circuit and the synchroscope—these were a few of the problems that were first met and successfully answered during the early years of Niagara operation. Niagara was not only a pioneer in the adoption of the alternating current polyphase system on a large scale, but it was also a pioneer in many of the specific methods, practises and devices that were essential to the ultimate success of that system.

Niagara marks an epoch in electricity. It stands as a monument to the greatest single step in advance that was ever taken in the electrical field.

Utica, New York, 1921.

P. M. Lincoln.

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PROF. GEORGE FORBES
F.R.S., M.I.C.E., M.I.E.E. (BR.)

Prof. George Forbes, of London, the principal advocate of the alternating current for long-distance transmission of electric power before the International Niagara Commission in 1891, who subsequently was one of the consulting engineers of The Cataract Construction Company in 1892–1894, calls attention, upon invitation to express his reflections upon a review of his relations with The Niagara Falls Power Company, to its action upon three points:

(1) *Foresight* in favoring alternating current, even at a date when no single alternating current motor was in commercial use.

(2) *Insistence* upon using low frequency alternations, although the majority of practical men insisted that such an innovation was incompatible with commercial success.

(3) *Persistence* with which were overcome the prejudices of American manufacturers and finally enlisted the whole-hearted co-operation of one of them to produce the only type of dynamo (that with the revolving external field magnets invented by the

company's engineer) that would be capable of supplying the angular momentum requisite for regulation of the turbines, without exceeding the limit of weight prescribed by their designers.

These three points, all received with violent opposition from outside, were the secret of your success in the electrical development, and have led all engineers of hydro-electrical developments all over the world to copy your pioneer, and therefore, experimental, scheme of construction.

I was very glad you were able to give me assurance of the financial success of the Niagara work. Many pioneer engineering works (e.g., the first Atlantic cable) have enriched the successors of the pioneers rather than the pioneers themselves. Your reward was not equal to your deserts, but it was, I am glad to note, substantial.

London, 1924.

George Forbes

PROF. WILLIAM CAWTHORNE UNWIN
B.SC., LL.D., F.R.S., MEM. AND PAST-PRES. INST. C.E.,
HON. LIFE MEM. AND PAST-PRES. INST. M.E.,(BR.)
HON. MEM. A.S.C.E., HON. MEM. A.S.M.E.

In response to an invitation to review his relations with the Niagara enterprise, a memorandum dated Kensington, January 1, 1919, was received from Professor Unwin, secretary of the International Niagara Commission at London, June, 1890 to March, 1891, where he was in almost daily collaboration with Dr. Coleman Sellers and other engineers, regarding the competition of projects and their final examination and selection for awards by the commission. Professor Unwin was subsequently retained by The Cataract Construction Company as a consulting engineer, in which capacity he made three visits to Niagara, where he took part in the solution of various engineering problems as the work proceeded. He wrote:

> In reply to your request to write you some reflections on my connection with the great Niagara installations, I find it rather difficult at this distance of time and in view of the enormous developments which have taken place in twenty-five years to put myself back in the position of 1890.

A full account of the International Commission and the projects submitted to it is given in a report[1] which I made to The Cataract Construction Company.

The projects were of extremely varied character. Hydraulic turbines of impulse and reaction types of from 2000 to 10,000 horse-power; distribution by electricity, by compressed air and by wire ropes. Most of the electrical schemes proposed direct-current production and distribution with varying current and constant voltage. Messrs. Siemens proposed constant direct current at varying voltage; Professor Forbes only proposed alternating current. From the first, electrical distribution of the power was in favor, but was not definitely decided upon until May, 1893.

Great changes in the plans were the result of detailed discussion in the United States, and the further study of the problem by manufacturers.

For the hydraulic installation, twin outward-flow turbines with vertical shafts were adopted, the weight of the shaft being water-supported and the dynamos being above ground. In some respects the outward-flow type of turbine is the least satisfactory, the regulation being not very efficient and the speed comparatively unsteady. But at the time no other type lent itself to so compact and economical a design. Nothing contributed more to the success of this hydraulic development than the admirable and then novel relay speed governing arrangements designed by Faesch and Piccard[2] which control the great regulating sluices of the turbines.

The consideration of the method of electrical distribution involved a difficult problem, and it was not till 1893, after three years' intensive study, that a system of alternating current was finally adopted. The design of alternating current dynamos and motors was in its infancy in 1891, and none of large size had been constructed. The striking experimental multiphase transmission at high voltage at the Frankfort Exhibition, in 1891, however, had much influence on the minds of electricians. A reduction in the frequency of alternations was found to overcome some of the difficulties of a multiphase system. Alternating current, the voltage of which can be varied by statical step-up or step-down transformers, has a flexibility and adaptability to different applications which, as can now be seen, made its use at Niagara indispensable to success. It is remarkable, nevertheless, that courage was found to decide in this sense in the case of so great an undertaking, because some of the foremost electrical authorities were doubtful about or opposed to the plans adopted.

In two special directions the conversion of mechanical energy into electricity has great advantages. One is in the production of intense heat for metallurgical operations; the other is in electrolytic and other chemical processes.

Within the sphere of material requirements the production, distribution and application of mechanical energy is the most vital interest of mankind. Human progress has largely depended on the supplementing or superseding of muscular energy by motive power produced by engines, amongst which water motors and heat motors are the chief and electric motors driven by current produced by these are important auxiliaries. Civilization may be measured by the degree in which human labor is replaced by power derived from natural sources of energy.

Hydraulic power, where it can be obtained, is cheaper and cleaner than heat power. The loss in health and wealth which has been incurred by atmospheric pollution by steam plants must be very great, although from habit it is usually ignored. For a long time the use of water-power was restricted to the area where it was produced. Hence, a hundred years ago, textile mills and even some metallurgical works spread into districts where water-power could be found. The combination of hydraulic power plants, electric transmission and electric motors which re-transform electric into mechanical energy removes all the obstacles to the utilization of water-power in industry. With the developments of hydro-electric stations the need for crowding workmen into factories and manufacturing towns in part disappears so that they can if necessary live with more healthful surroundings.

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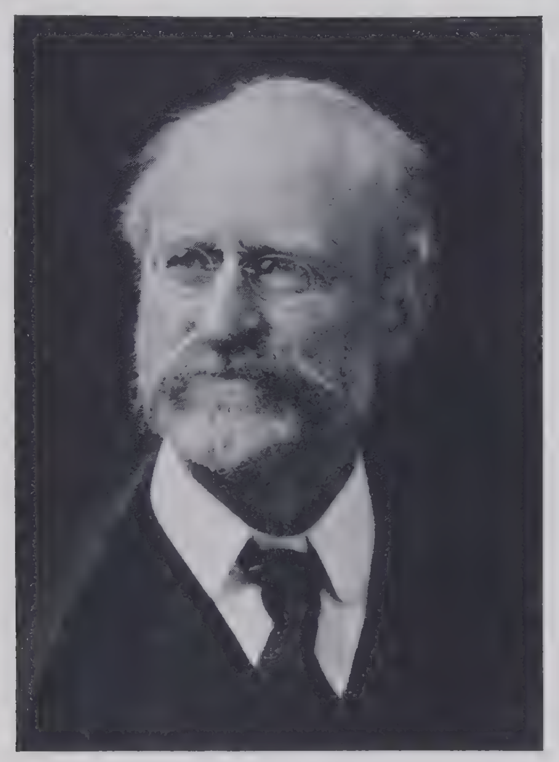
[1] Report on the Projects Submitted to the International Niagara Commission, New York, 1891.

[2] Of Geneva, Switzerland.

Electrical transmission permits the distribution of power from a central station to long distances and over a wide area. The facility it affords for subdivision, accurate measurement and control enables it to be supplied to many consumers. This again favors the equalization of the load at the central station and reduces the loss due to machinery standing idle. It is possible to encourage electro-chemical industries and to arrange that they should take current when it is least required by other industries, and then the energy can be supplied very cheaply. Hence the development of electrical energy may in course of time greatly improve the conditions of life. At Niagara some 7,000,000 horse-power which might have been available for industrial purposes was being wasted. The conditions were favorable for utilization in other respects for the fall was a high one and the Great Lakes from which the water flows act as reservoirs equalizing the supply. The installation has been carried out with complete success, and it is the first large scale undertaking of the kind. It has been the parent of many others in different parts of the world, or at any rate showed the way to others to achieve a similar success. But the risk of misadventure in so novel and complicated an enterprise in the days when it was carried out was great, and that no serious mistake of judgment or calculation occurred witnesses to the remarkable care with which the preliminary investigations and discussions were conducted.

Kensington, 1919.

W. C. Unwin



Clemens Herschel
HON. MEM. AND PAST-PRES. A.S.C.E.,
MEM. INST. C.E.

A similar invitation to present here a review of his connection with the Niagara enterprise brought the following memorandum from Clemens Herschel, past-president and honorable member American Society of Civil Engineers, who served as hydraulic engineer for the cataract company from January 1, 1890, until the close of its construction activities.

"What Hath God Wrought!"

(Numbers, XXIII-23)

In considering the changes that have taken place since 1889, in the generation and distribution of primary power, one can not help being reminded of the first message sent over the wires by Samuel F. B. Morse, from Baltimore to Washington, given at the head of this memorandum.

Within the lifetime of so many of us, the art of electric transmission has been led to develop from the sending of a few faltering, feeble signals, over a length of thirty or forty miles, to the conveyance for ten times that distance, and of hundreds of thousands of horse-power. A potent factor in this evolution was the so-called "Harnessing of Niagara" in the last decade of the nineteenth century.

Yet was this development attained at a great cost of labor, and at the offering and venture of many millions of latterly much decried, accumulated, hard-earned money, or what is known as "capital."

It seems so natural at the present time (1923) to tap a power circuit for the acquisition of thousands of horse-power, though the primary source of the same may be hundreds of miles away, that it is difficult to realize that no longer ago than 1890, it was very much of a question whether to disperse and distribute 20,000 horse-power by means of wire rope, by compressed air, or by electrical transmission. Even after electrical transmission had been decided on, it required the momentous decision of The Niagara Falls Power Company, in favor of the alternating current, and against the use of the direct current, to give the first named method a world-wide impetus and commercial advantage; one it has maintained to the present day.

This decision naturally reacted on the whole plan of the works. As was wont in New England hydraulic engineering circles, such a case as that presented by Niagara Falls could properly be solved only by the system of each manufacturer generating his own power on his own premises. To send power to Buffalo, twenty miles away, in substitution for its steam power, was a make-weight to the enterprise; to be solved later on, or abandoned, as the enterprise developed. The great exemplar was the system used by the several American water-power undertakings at Paterson, New Jersey; Lowell, Lawrence and Holyoke, Massachusetts; smaller companies all over New England; at Cohoes, New York; some in Ohio, Wisconsin, Minnesota, Georgia and elsewhere.

This American system owes its corporate origin to no less a man than Alexander Hamilton; possibly to others working with him in 1791, to establish "The Society for Establishing Useful Manufactures" at the "Great Falls of the Passaic River," in Paterson, New Jersey; one of whom was Major L'Enfant, the same military and civil engineer who was the author of the plan upon which was laid out the nation's capital, in the District of Columbia. To these two, the lawyer and engineer of the infant company, is owing what was then a new method of utilizing the power of a river. They invented a system of canals and mill-sites, and agreements for the leasehold of such mill-sites, with a system of perpetual rentals for the water rights appurtenant to these mill-sites, under which the development of manufacturing in the United States prospered greatly. It could not be imitated in Europe, and only occasionally in the United States, because in those older countries, and even in the United States in many instances, land in compact bodies, upon which to build such works, could not be bought; and until the advent of power distribution by electricity, the conception of generating power, and distributing it for a "public use," was difficult of comprehension (as it yet is in some quarters); hence no "powers of eminent domain" to take the necessary lands could be brought into action.

All this has been changed by invention and works, of which those at Niagara Falls in 1889 were a notable pioneer and example, until now they have become so commonplace and so numerous that many men of the present time clearly foresee the day when, scouting state lines and physical obstacles, the whole United States will be able to draw power from a national body of power-houses and power lines; after the manner of the telephone service enjoyed by the people of 1923.

This same advance has rendered obsolete the good old American system of water-power companies; kept alive now mainly by the fact of the distribution of its lands and rights among numerous manufacturers who use the power, and use it under perpetual contracts. In some such cases, the present value of the land alone to be gained for building and park purposes by the abandonment of the old system of canals, would pay for replacing it by one-power station, and the distribution of its power by wire.

All honor, therefore, to the persevering work of those who at Cohoes, and to a large extent also at Paterson, have already brought about the change above described.

These are fundamental changes in the concept of the works that produce the power. No less marked are the changes naturally brought about in the use of power produced. Quite recently it has been pointed out by a marked example, what an advantage there lies in the element called the "diversity factor," even over the sale of high constant 24-hour power; one endowed with the much sought after 100 per cent "load factor."

Thus the power at Niagara Falls, used largely by continuous electro-chemical processes, is probably nearer a perfect 24-hour continuous power (100 per cent load factor) than any other in the country. The Commonwealth Edison Company of Chicago on the other hand, sells power for the most diverse purposes. Were all of its consumers, at one and the same time, to use all the power each one of them is entitled to draw, the works would be obliged to acknowledge themselves unable to supply the half of the then demand.

Yet let it not be said that the works at Niagara do not cater to diverse uses. Chicago serves its various customers of diverse nature directly by the delivery of power. Niagara serves a multitude of diverse customers throughout the United States and foreign countries, by means of its products—ferro-alloys, abrasives, fertilizers, chlorine and what not of chemicals—originally produced in the one city of Niagara Falls. How important some of these chemical products are, may be gleaned from the fact that when, during the World War, it became a question of the relative needs of the people for the products of factories, in order that they might receive any power, some of these Niagara chemical works were accorded the very first place.

These remarks might be extended almost indefinitely. Enough has been said, however, to indicate in some measure the trend of the times we live in. The choice of Samuel F. B. Morse for the first message to be sent over the wires has a little of finality about it; as though not much of development were to follow after. Let us recognize that "the half hath not been told."

Progress in a direction, the end and aim whereof no man can discern, is still with us. Rather let us say: (Daniel, XII-6) "How long shall it be to the end of these wonders?"

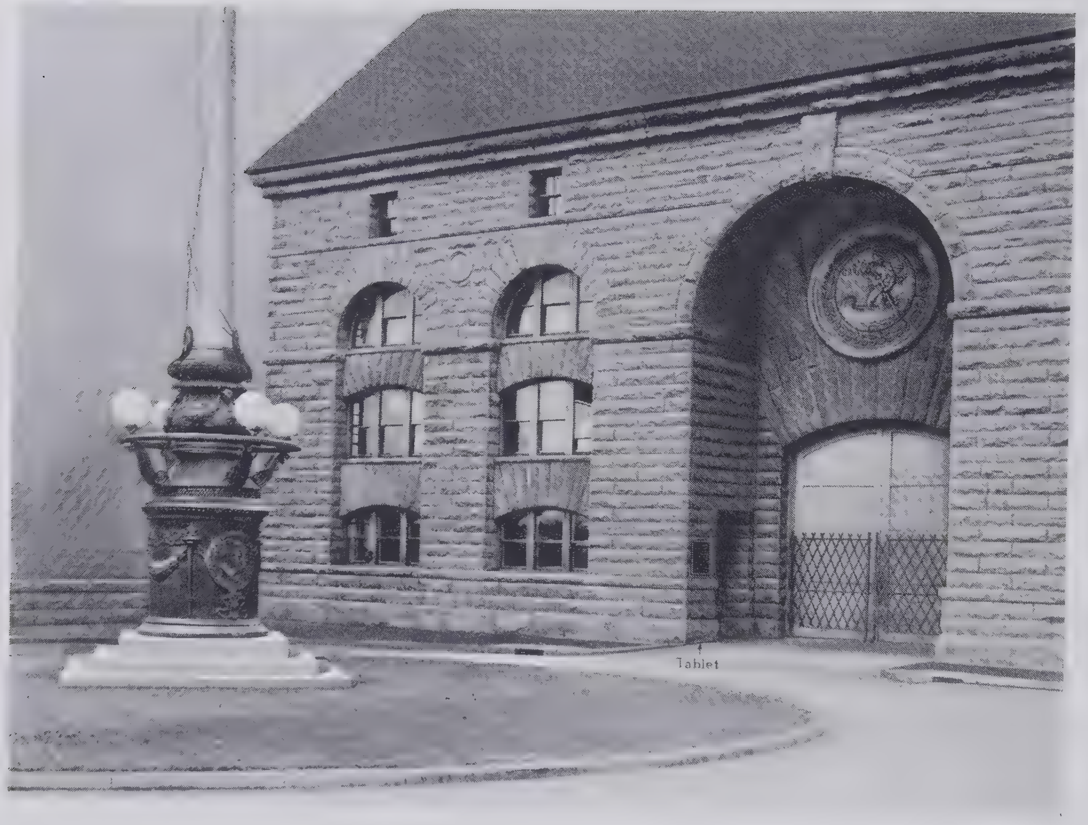
New York City, 1923.

Clemens Herschel.

THE AUTHOR OF *Niagara Power* IN REFLECTIVE MOOD
THE NIAGARA STUDY, 1927

REFLECTIONS

CHAPTER XXIX



ENTRANCE TO POWER-HOUSE NUMBER ONE, WITH BRONZE MEMORIAL TABLET ERECTED IN DECEMBER, 1924, AS TRIBUTE TO HYDRO-ELECTRIC PIONEERS, IN PLACE

GUESTS PRESENT AT UNVEILING OF MEMORIAL TABLET, JANUARY, 1925

Left to right—On platform: G. S. Anderson, W. K. Bradbury, G. B. Mathews, E. D. Adams, P. A. Schoellkopf, M. Cohn, Jr., and J. F. Schoellkopf. Standing: A. Schoellkopf, R. J. H. Hutton, H. Acres, G. R. Shepard, Gen. Guy E. Tripp, LeGrand S. De Graff, F. D. Corey, A. M. Grier, Prof. C. F. Scott, W. H. Onken, Jr., J. E. Montague, Col. J. G. Warren, W. P. Little, R. R. Coddington, F. L. Lovelace, Dr. W. F. Durand, G. F. Rand, C. F. Rand, N. F. Maddever, A. E. Kennelly, O. D. Dales, F. S. McGraw, De L. Rankine, W. Laughlin, C. R. Huntley, A. C. Deuel, W. D. Olmsted, C. A. Tattersall M. L. Clark, A. D. Robb, L. E. Imlay

REFLECTIONS

CHAPTER XXIX

IT is pleasant to view in retrospect the history of The Niagara Falls Power Company, for are not the accomplishments of the past but the dawn of those to come? To have dreamed dreams and then as the years rolled by to have seen and to have taken part in realities exceeding in grandeur and magnitude the product of one's imagination is indeed a rare experience.

But, then, who could have visualized or pictured even in dreams the magical growth and wonderful attainments of the electrical industry at the time the first Niagara development was under contemplation? The very decision to adopt alternating-current electricity in preference to compressed air and to transmit electrical energy from Niagara Falls to Buffalo, a distance of 25 miles, was considered at the time extremely bold and hazardous.

The art was then nebulous and its future dubious. Indeed, the size of the first water-wheel and alternator was so stupendous in comparison with existing water-wheels and dynamos, that many men engaged in the business looked upon our plans for developing Niagara power as utopian and expected to see the whole enterprise burst like a bubble. In their estimation Ponce de Leon in his quest for the fountain of perpetual youth exhibited just as much sense as we did in our attempt to harness the raging torrent at Niagara. Had not men tried before and failed? But

"Errors like straws upon the surface flow;
He who would search for pearls must dive below."

Naturally, with the history and experience of these previous ventures before us, we were not without misgivings. We were determined, however, to build on certainties and not on doubts. That there were millions of water horsepower available in the Niagara River was unquestionable. How to develop that power and then to dispose of it were problems which up until 1890 baffled the engineering world. Thanks to the world-wide investigation which we undertook at that time and out of which grew the plans for the first Niagara installation, there are no longer any engineering inhibitions to hydro-electric development and transmission of power anywhere.

Seldom, if ever, were greater pains taken in planning and executing a commercial venture. We fortified ourselves against failure by consulting the best engineering talent in the world. Financial stability and independence were accorded the enterprise from the outset, and so great became the interest in the Niagara development and so widespread became its fame that scientists, statesmen, captains of industry, and others came from every land and clime to behold the greatest hydro-electric installation in all the world, exceeded in scientific and popular interest only by the greater grandeur and magnificence of the mighty cataract from which the development derived its power.

Thus one cannot recall the history of Niagara power without retrospect giving way to prophecy, prediction taking the place of review. Stimulating suggestion of coming developments supersedes commentary on the growth of a system, and inspiration to future endeavor crowds out vainglorious recital of past achievement.

Laying aside the contemplation of the accomplishment at Niagara Falls, it is gratifying to dwell for a moment on the really great influence it has wielded on the electrical and allied arts. The lessons Niagara power has taught are universal in their application and the triumphs for which Niagara power stands are more enduring than monuments of stone, for they are now a part of the world's progress. It is true that many milestones are to be found along the roadway marking electrical progress; but steps make progress, and whereas the first electrical installation at Niagara Falls was revolutionary in its character, subsequent developments have been evolutionary.

The original Niagara installation was great not simply because it brought together the latest developments of the genius of civil, mechanical, and electrical engineers—which was a great achievement in itself—but because it succeeded in establishing and diffusing exact knowledge on hydro-electric generation and transmission of energy in large quantities and thus advanced the cause of human betterment and world progress. Whither the inspirations thus stimulated will lead is difficult to measure or anticipate. Upon the broad foundations laid by the pioneers at Niagara Falls has been erected the great electrical structure we see today.

In the light of greater experience and advances made in the art, engineers now are planning and executing electric generating and transmission schemes outrivaling in interest and in the extent and diversity of territory served that of The Niagara Falls Power Company. However, nowhere on the face of the earth are there installations of the magnitude and efficiency of those at Niagara, nowhere else is electricity generated in larger quantity, and there is no place of importance on the civilized globe where the influence of Niagara power is not felt or where its benefactions are not manifest. Of a truth, "No gift from nature's storehouse renders greater service than the waters of Niagara."

It would be idle and vainglorious to contend that we visualized all this when we planned the first installation at Niagara Falls. Daniel Boone and a few struggling hunters, as they passed through the gap in the Alleghanies long ago, little thought that they were the van of a mighty empire. Neither did we when we organized The Niagara Falls Power Company dream that Niagara Falls would become the home of the electrochemical and electrometallurgical industries and the birthplace of power development on a grander and larger scale than ever before attempted.

Indian lore and romance there were at Niagara Falls when Hennepin first beheld it. The mystic sacrifice of an Indian maid to the God of Waters has moved poet and painter to creative art; but reality has out-stripped imagination in the utilization and practical application of the power of Niagara Falls in every-day life.

A new era in electric lighting began on both sides of the Atlantic shortly after the Belgian inventor, Gramme, introduced his dynamo-electric machine in the early seventies. In America all the initial lighting work from central-station sources was done, however, by means of direct or continuous currents, which were employed alike for arc and incandescent lighting. The supply of current for stationary motors for power purposes constitutes a very important element of the electric light and power business today, and while the work of such men as Edison, Brush, Thomson, Draft, Sperry, Hochhausen, Sprague, Curtis, Crocker, Wheeler, and Weston soon resulted in the development of highly efficient motors capable of application to the widest range of industrial requirement, the early motor, like the early lamp, operated on direct current.

The next step forward was the development of single-phase alternating current; with the inventions of Stanley in transformers and of Tesla in polyphase motors the entire art of electric generation and utilization was changed. It was at this critical juncture, before their work was thoroughly tested, that The Niagara Falls Power Company was formed. Our decision to adopt alternating current in the world's greatest power-house settled all doubt as to the universal adaptability of alternating current and laid the foundation for the marvelous electrical development which followed; for Tesla's work received its first extensive application on the system of The Niagara Falls Power Company.

It is interesting to note in this connection that the first hydro-electric station in this country started at Appleton, Wisconsin, on September 30, 1882. It was a very modest plant, housed in a wooden shed, and containing a single Edison dynamo capable of supplying energy to 180 10-candle power incandescent electric lamps. Niagara was the first superpower station in the world. Until it was started there were no steam engines or water-wheels built in this country in excess of 1000 horse-power rating. Not even the knowledge of what was being prepared for Niagara Falls had led to their manufacture.

Unfortunately no general statistics on the output of electric light and power stations in the United States were available until the government census of

1902. At that time the power stations at Niagara Falls were generating approximately one-fifth of all the electrical energy produced in the United States. The importance of Niagara Falls as a power center was, of course, recognized, but no one imagined that in 1902 there was being manufactured at Niagara Falls, New York, as much electricity as was being produced in the combined states of Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maine, Maryland, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, North Dakota, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Vermont, Virginia, Washington, West Virginia, Wisconsin, Wyoming, and the then territories of Arizona and Oklahoma—thirty-one states and two territories.

Of course, the electric light and power industry experienced phenomenal expansion after 1902, so that the output of The Niagara Falls Power Company does not now form so large a part of the whole. But the significant fact is that The Niagara Falls Power Company did not stop with its initial development. It kept on growing. It was the largest company in point of output at its inception, and it holds that leadership to this day. While the present Niagara system generates approximately one-fifteenth of the total energy for the United States, it would generate more if conditions permitted. The demand for Niagara power has never been satisfied, but the amount of water which may be diverted from the Niagara River for power purposes is fixed by international treaty, and not until that treaty is revised can The Niagara Falls Power Company generate more electricity at its present site. That the company has always given a good account of its stewardship and from the first has recognized its obligations to society in general may be gleaned from previous chapters. The entire electrical industry is in its debt for an educational influence of great value, for a permanent milestone on the high road of progress, and, not the least, for the great and permanent good it accomplished in making abundant electricity available for the then budding electrochemical and electrometallurgical industries.

The story of the development of these industries at Niagara Falls reads like a fairy tale. While the possibilities of many of the present electrochemical processes were recognized years ago, their commercial development necessarily was dependent on the production of abundant and cheap electricity. No sooner were our plans for harnessing Niagara Falls made known than men interested in the embryonic industries made inquiries concerning electrical power and shortly thereafter established factories at the falls.

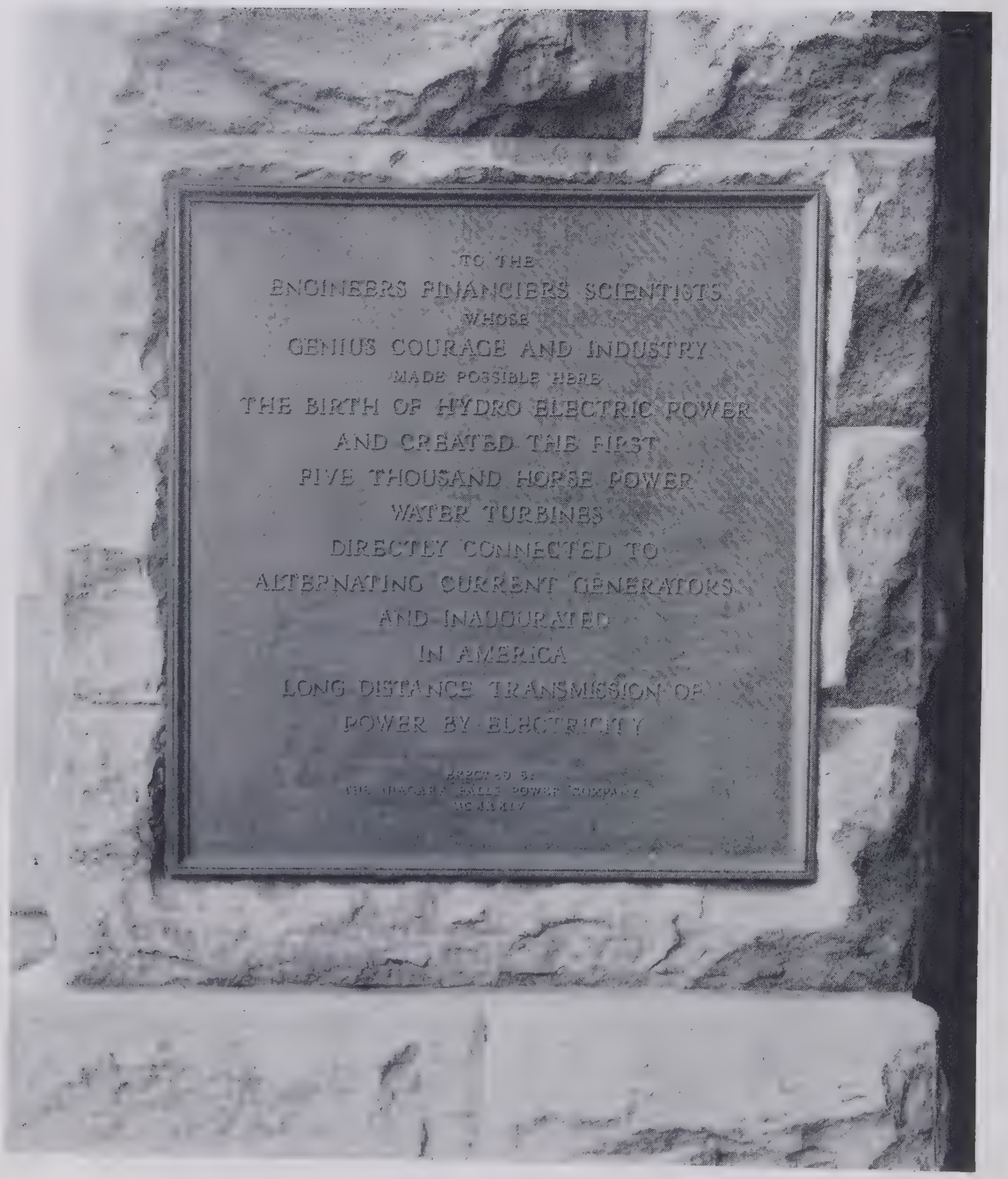
First came the aluminum industry; then the carborundum and the carbide industries, followed by numerous others. All of the processes being new, had, of course, to be developed, and in addition a market for the products had to be created. The dawn of the twentieth century was marked by the birth of the electrochemical industry at Niagara Falls where it seemed like Minerva to have sprung forth fully armed from the brain of Jove. The names of such men as Hall, Acheson and others will be forever associated with the wonderful achievements and development of the industry at that time and also with Niagara Falls where they performed their best work.

Fortunately, Niagara Falls offers other inducements to electrochemical and electrometallurgical industries besides cheap power. It is ideally located as a center of supply and demand and possesses good transportation, thereby enabling the manufactured products to be carried to their ultimate destination without heavy freight charges. The necessity for cheap power in large quantities has been one of the prime factors in the past development of the electrochemical industry and it is bound to remain one of the controlling factors in any question of this kind and oftentimes the deciding factor.

Limited, however, in their legitimate expansion at Niagara Falls as the electrochemical and electrometallurgical industries are by the quantity of power at present available, some companies have found it expedient to start additional factories elsewhere; and although industries like the aluminum, for example, may prosper at other sites, the great majority of them cannot move from Niagara Falls without increasing the cost of their product to the public because of the differential in freight on both raw material and finished product, higher cost of power and less advantageous labor market.

It is, therefore, evident that The Niagara Falls Power Company was the cause for the establishment and expansion of the electrochemical and electrometallurgical industries at Niagara Falls, and not the result. Tracing a kilowatt hour from the time it leaves the switchboard at Niagara Falls through these industries and thence through the steel or automatic industries, one is not only impressed with the tremendous importance of the electrochemical and allied interests located at Niagara Falls, but is also struck with the larger aspects of Niagara power, hidden though they may be, in the form of an automobile or other high-grade steel product, or in the chlorinated and purified drinking water that one draws from the faucet.

The value of the products dependent upon Niagara power is reckoned in billions of dollars annually, whereas the gross earnings of The Niagara Falls Power Company from the largest and finest hydro-electric development in the world was $8,549,269.83 in 1926. The tax budget for 1926 was $1,508,794.94.



TO THE
ENGINEERS FINANCIERS SCIENTISTS
WHOSE
GENIUS COURAGE AND INDUSTRY
MADE POSSIBLE HERE
THE BIRTH OF HYDRO ELECTRIC POWER
AND CREATED THE FIRST
FIVE THOUSAND HORSE POWER
WATER TURBINES
DIRECTLY CONNECTED TO
ALTERNATING CURRENT GENERATORS
AND INAUGURATED
IN AMERICA
LONG DISTANCE TRANSMISSION OF
POWER BY ELECTRICITY

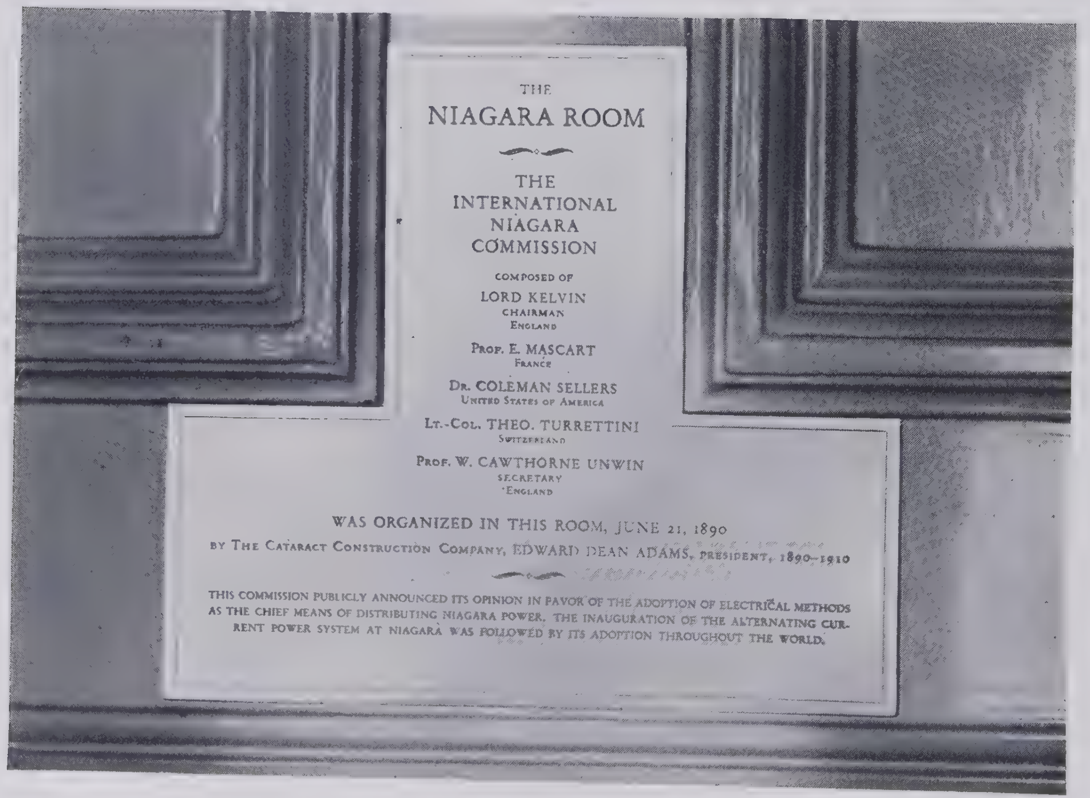
Memorial Tablet Erected at Portal Entrance of Power-house Number One, December, 1924 thus making The Niagara Falls Power Company not only one of the real conservers of natural resources (its power-houses operate at an efficiency of 90 per cent) but a source of income to the state and a benefaction to the industries and citizenry of the nation.

Many engineers acquired fame and eminence in connection with their work at Niagara Falls. Three of the executive engineers and two of the consulting engineers connected with The Niagara Falls Power Company became presidents of the American Institute of Electrical Engineers and another became president of the American Society of Civil Engineers. The gold medals awarded annually by the American Institute of Electrical Engineers, through its Edison Medal Committee, seven out of sixteen have been awarded to men associated more or less with the Niagara enterprise or for meritorious achievement in connection with the development of alternating current. These medalists were Elihu Thomson, George Westinghouse, William Stanley, Nikola Tesla, Benjamin G. Lamme, William LeRoy Emmet and Cummings C. Chesney.

Many engineering graduates sought positions upon the staffs of The Cataract Construction Company and The Niagara Falls Power Company, because the opportunities for familiarity with advanced scientific work, not yet described in books, were unique. The services of these engineers after several years' experience at Niagara were eagerly sought elsewhere, and they became leaders of men and captains in industry.

It is not easy to estimate how vast are the changes in industrial, civic and domestic life that have taken place since the first recognition of the new era at Niagara Falls. Especially in hydro-electric development and electric transmission of energy have these strides been made since Niagara showed the way. For a time the significance of what was being done at Niagara was unappreciated except by a few engineers, and its growth unobserved because unexpected. Suddenly it burst its bonds and emerged a young giant eager to engage in a prodigious struggle with other forms of power for supremacy.

The industrial revolution which followed was more potent, more far-reaching and lasting in its effects especially along the Niagara frontier than any political upheaval of modern times. It brought with it a change immeasurably more profound in all its implications than the age of steam and secured to millions of men, women, and children, great personal comfort and happiness. One has only to look back a few years to see how electric power harnessed to serve mankind has expanded, developed, deepened, and strengthened his physical potentialities and enriched living standards far beyond expectations. The credit for all this does not, of course, belong to The Niagara Falls Power



THE
NIAGARA ROOM

THE
INTERNATIONAL
NIAGARA
COMMISSION

COMPOSED OF

LORD KELVIN
CHAIRMAN
ENGLAND

PROF. E. MASCART
FRANCE

DR. COLEMAN SELLERS
UNITED STATES OF AMERICA

LT.-COL. THEO. TURRETTINI
SWITZERLAND

PROF. W. CAWTHORNE UNWIN
SECRETARY
ENGLAND

WAS ORGANIZED IN THIS ROOM, JUNE 21, 1890
BY THE CATARACT CONSTRUCTION COMPANY, EDWARD DEAN ADAMS, PRESIDENT, 1890–1910

THIS COMMISSION PUBLICLY ANNOUNCED ITS OPINION IN FAVOR OF THE ADOPTION OF ELECTRICAL METHODS AS THE CHIEF MEANS OF DISTRIBUTING NIAGARA POWER. THE INAUGURATION OF THE ALTERNATING CURRENT POWER SYSTEM AT NIAGARA WAS FOLLOWED BY ITS ADOPTION THROUGHOUT THE WORLD.

NIAGARA ROOM, BROWN'S HOTEL, LONDON, SHOWING PLATE COMMEMORATING THE ORGANIZATION OF THE INTERNATIONAL NIAGARA COMMISSION, JUNE 21, 1890

Company, but this company was a pioneer in a critical period of power development. A first far-reaching decision was made in 1890, when it was decided to generate hydraulic power in a large central station for distribution to many users instead of using the old-time method of letting each mill be driven by its own wheel. Other pioneer steps were taken in adopting electricity in a great power project, and in selecting polyphase current as the system to be used.

Even our company was so absorbed at the time with the attractiveness of the market for electric lights and motors in Buffalo that we forgot about Niagara Falls. To us, as to others, the grass in our neighbors' yard looked greener than the grass in our own. Little did we imagine that so much power would be utilized at Niagara Falls itself. But we did have faith in hydro-electric development and in the transmission of electricity. We did see the advantage of transmitted power to industry and its relation to natural resources. What we did was in a measure experimental. We planned carefully and with an eye to the future.

The water at Niagara Falls did not then have the value it possesses today so that the original development was not so efficient in the use of the head available as the later stations of the company were, or as a new station would be tomorrow. Our right to use the water was at first unquestioned, but subsequently, because of our enterprise in proving it to be of value for power purposes, the right was challenged by both the state and national governments. But in recognition of our work at Niagara Falls and in appreciation of its nation-wide significance, The Niagara Falls Power Company was granted the first licenses issued by the Federal Power Commission under the new law governing power production on navigable rivers and on the streams in the public domain.

Of course the novelty in Niagara power and of hydro-electrical development and high-tension transmission of electricity is now gone; but it is befitting, nevertheless, that suitable recognition of an event of such historic importance and fraught with such tremendous consequences to the engineering world should be made. It was, therefore, with much gratification that the author as the sole survivor of the pioneer directors of the original Niagara Falls Power Company viewed the unveiling of a tablet on the wall of the portal entrance of Power-house Number One commemorating not only the work of the engineers and scientists whose genius, courage, and industry made Niagara power possible, but also the important albeit less spectacular work of the pioneer officers and directors who financed the big project.

These friends and associates had like myself their established business connections as bankers, capitalists, and lawyers. With the exception of the secretary and treasurer, William B. Rankine, who devoted his entire attention to Niagara matters, these men gave their time and thought to the direction of the great enterprise as a diversion, an intellectual stimulus and a friendly companionship in an international study of scientific industrial development. With one exception, A. J. Forbes-Leith, Lord Leith of Fyvie, Scotland, they all resided in New York, and their vocations and affiliations were as follows: Edward Dean Adams, president, banker of Winslow, Lanier & Company; Francis Lynde Stetson, lawyer; Edward A. Wickes, capitalist; William Birch Rankine, lawyer; John Jacob Astor, capitalist; John Crosby Brown, banker of Brown Brothers & Company; Walter Howe, lawyer; Joseph H. Larocque, lawyer; Darius Ogden Mills, capitalist; George S. Bowdoin, banker of Drexel, Morgan & Company; Charles F. Clark, president of Bradstreet Company; Charles Lanier, banker of Winslow, Lanier & Company; and Frederick W. Whitridge, lawyer.

More recently there was placed in the salon of Brown's Hotel, London, where the conference of the International Niagara Commission was organized, a brass plaque[1] commemorating the epoch-making services rendered by the international scientists forming the commission and serving as a historical record of that important event. A view of the room with the plaque in position on the door, and an aeroplane view of Niagara Falls on the wall is given on page 374 of this chapter.

The commemorative tablet which adorns the entrance of the first power-house at Niagara Falls where alternating current applied to hydro-electric generation on a large scale won its first triumph and the tablet affixed to the wall of the room in Brown's Hotel, recalling the meeting there of the International Niagara Commission, whose courage and faith wrought the victory, bring to mind the "Centennial Hymn" in which Whittier sought "our fathers' God" to

> Be with us while the New World greets
> The Old World thronging all its streets,
> Unveiling all the triumphs won
> By art or toil beneath the sun,
> And unto common good ordain
> The rivalship of hand and brain ******
>
> For art and labor met in truce,
> For beauty made the bride of use.

---

[1] A facsimile of the plaque is given in Chapter IX, page 178, Volume I. On page 177 is a view of the room showing the only survivor of the pioneer directors (the author of this work).

FINAL CONFERENCE FOR REVIEW OF ALL THE PROOFS OF THE TWO VOLUMES OF *Niagara Power*, FEBRUARY 18, 1927

Held in the Niagara study at the apartment of Edward Dean Adams, 920 Fifth Avenue, New York, in which this history has been prepared. Reading from left to right: William H. Onken, Jr., publication adviser; Paul A. Schoellkopf, president, The Niagara Falls Power Company; Edward Dean Adams, author; Edward E. Bartlett, publisher; Charles F. Scott, publication adviser; George S. Anderson, publication adviser. The publication advisers were appointed by The Niagara Falls Power Company to represent its interests in preparing the manuscript of *Niagara Power* for publication.

HERE ENDS THIS NARRATIVE OF THE COURAGEOUS ENDEAVORS OF MEN, DURING A CENTURY OF SACRIFICE AND DISCOURAGEMENT, TO CONTROL SOME OF THE FORCES OF NATURE AT NIAGARA

HOMAGE

IN CLOSING *there should be recorded a tribute of appreciation to those pioneers whose energy, faith and perseverance will ever command the admiration of posterity.*

TO THE ASSOCIATES *in the enterprise of thirty years, who overcame doubt, conservatism and prejudice by their courage, thoroughness, persistence and forethought, and wrought success in their great endeavor, let there be also here expressed appreciation of their efforts, admiration for their courage, praise for their loyalty, and gratitude for their support, all contributing to the triumph that was won for their undertaking.*

THE FEW SURVIVORS *of these groups unite in this testimonial of admiration, honor and affection for their companions, whose memory will be cherished to the end.*

Edward D. Adams.

Volume Two

APPENDICES H–T

APPENDIX H

"A RUN OF STONE"

"A RUN OF STONE"

"A run of stone" is a pair of grindstones such as was used in the early mills for preparing meal and flour. As the amount of power required to operate a pair of grindstones would depend on many factors—the chief of which would be the weight of the stones and the speed at which they revolved—it is natural that the amount of water-power corresponding to a "run of stone" should be quite indefinite. An English authority states it to be from four to eight horse-power. If human nature was the same fifty years ago as it is now it seems probable that having a contract for an amount of water under a given head sufficient to operate a "run of stone," the miller would gradually increase the size of the stones and perhaps their speed, thus increasing the amount of meal ground, and still demand the water to operate them.

This old unit of power was not standardized and was given different values in different localities. The hardness of the kernel of wheat or corn, varied from dry to moist season, and the fineness or coarseness of the product made further differences in the amount of millstone power required to produce grist from the mill.

Whitham, who states that he had personally examined 52 grist mills in 12 states, concludes that a "run of stones," with its accompanying machinery, called for:—

30 to 40 horse-power in a first class Merchant Mill yielding 85 to 100 barrels per day;

20 to 25 horse-power in a second class Merchant Mill yielding 50 to 60 barrels per day;

12 to 15 horse-power in a common country Grist Mill.

APPENDIX I

TUNNEL INSPECTION

JUNE 1, 1902

HARNESS ON AGAIN

(Special to the *Buffalo Express*)

HARNESS ON AGAIN

Probably Not for a Century Will the Flow in the Niagara Tunnel Be Stopped

Inspection Yesterday

Engineers Walked Through Huge Boring and Saw That Their Plans Had Been Good

(Special to the *Buffalo Express*)

June 2, 1902

Niagara Falls, June 1, 1902.—The inspection of the mammoth tunnel of The Niagara Falls Power Company was successfully accomplished this morning by a party of engineers and the tunnel was found to be in as perfect condition as it was the day it was finished. That it was so is a very definite triumph for the American contractor, the American engineer, to say nothing of the American capitalist.

Niagara Falls power and Buffalo's reputation as a power center are largely predicated upon a tube bored for a mile and a third below the city of Niagara Falls. Running from the intake of The Niagara Falls Power Company to an outlet below the falls, right at the upper steel-arch bridge, a horseshoe-shaped tunnel that carries away the water after it has turned the turbines and done its duty was bored at the expense of several millions. Twenty-one feet high and 18 feet, 10 inches wide at its widest part, it carries off 4600 cubic feet of water every second at the present time and when the new wheel-pit is running it will carry off 9000 cubic feet. There is no such tunnel elsewhere in the world.

There are 32,400,000 cubic feet of water discharged from the tunnel every hour at the present time. That is a considerable river. This tunnel, in fact, could take two rivers the size of the Connecticut as it runs by Holyoke and discharge them. Enormous as the amount is, it is a very small fraction of the amount that flows over the falls instead of taking the tunnel route. Twenty-nine drops out of 30 take the route prescribed by Nature, one drop the route devised by man. There is little ground for the sentimentalists to stand on who say the falls lose in beauty when they gain for industry. Early this morning when the power was turned off there was not the slightest difference seen at the cataract. Even though two rivers of the average size of the Connecticut had been added nothing would be seen to indicate the increase.

It was highly important that ten years' use of the tunnel had not harmed it. No one in the inspecting party knew what would be found. The capitalists hoped, the engineers wondered if their knowledge had proved sufficient. At the end of the inspection Clemens Herschel, the most eminent hydraulic engineer in America, said: "The tunnel is good for 100 years more at any rate." He said it with satisfaction. It was heard with no less satisfaction. And in the 100 years it is highly probable that no inspection of the tunnel will be made.

This morning at one o'clock members of the inspection party gathered to prepare themselves for the journey. Rubber suits, boots and hats were put on and the journey was started. Before this time Niagara's industrial heart had gradually ceased to flutter. One by one the dynamos were stopped. The big manufacturing plants had ceased running, many of them for the first time in years. At last the power which runs the street cars and electric lights in Buffalo was taken away and the big steam plant was used to operate them in the old-fashioned way. The mammoth dynamos which had but a few moments before been running at a rate of 1¼ miles a second had become still. At 1.07 o'clock not a wheel was stirring.

Niagara's power was still for the first time since July 26,1897, and for the only time probably this century. When the new wheel-pit is finished and in operation it will be almost impossible to still the industrial giant. Every time there is a shut-down, the users of power have to be reckoned with, forewarned, and, if necessary, indemnified for the loss they experience. Niagara gives a continuous power—an interruption of the continuity is a serious thing.

The exploring party, outside the regular employees and the men engaged in removing the bulkhead, consisted of W. B. Rankine and E. D. Adams, representing the board of directors of the power company; Clemens Herschel, the hydraulic engineer; W. A. Brackenridge, P. P. Barton, W. K. Giboney, L. E. Imlay, A. H. Van Cleve, and C. C. Egbert, of the power company, and the correspondent of the *Buffalo Express.*

The bottom of Wheel-pit No. 1 was reached, the connecting tunnels between the two wheel-pits passed through, the new wheel-pit entered, whence by a descent by ladder the new tunnel which discharges Wheel-pit No. 2 into the main tunnel was entered. This is 600 feet long. At its end was a huge bulkhead built of heavy timber, sheathed with planks and tightly caulked. This bulkhead was disappearing under the vigorous work of a force of workmen and the connection between the old and the new was being made.

Beyond the bulkhead was the old tunnel. The exploring party, carrying lanterns and searchlights, entered it.

The tunnel is lined with 16,000,000 bricks set in some 70,000 tons of Portland cement. The water had all receded save the little that came from the gates at the wheel-pit, making a stream about a foot and a half wide of great swiftness. The walls of the tunnel were at once seen to be as solid as a drumhead. A curious little formation was seen here and there, which formed like an inner coating on the brick and acted as an interior sheath here and there, making the walls stronger than ever.

In the blackness ahead the party went closely, examining the walls and roof. Not a brick was dislodged or cracked. Here and there a thin stream of water, about the size of a pin, shot from the walls. That it was better than expected was seen from the faces of the party under their great rubber hats.

It was easy walking with the current, and the mile and a third under the heart of the city, 200 feet below the surface, was easily traversed until the portal was reached. The smaller tunnel of the International Paper Company's plant was also investigated and found to be perfectly sound.

The party made a curious picture. Behind, the noise of the workmen, accentuated and exaggerated by the form of the tunnel, sounded with giant boomings. The shouts of the men, the flare of the torches and the sharper light of the lanterns, and here and there the eye of a searchlight carried by Assistant Superintendent Egbert, made a strange effect to the eye and ear. Underneath the swift rushing water, carrying bits of the detached bulkhead, made walking precarious, as the floor of the tunnel slopes.

Walking back was not an easy task. The sides of the tunnel were hugged and were slippery. Overhead, the roof looked black, with white patches. The sides were a clean red, kept bright by the rush of water. The engineers measured the water line and to their satisfaction found that there was room still for the water for the eleven new dynamos that will be in operation when the new wheel-pit was finished. The calculations of a dozen years ago were found to be correct.

It must be remembered that the planners of The Niagara Falls Power Company's plant had to blaze their own way. There was no precedent for many of the problems to be worked out. They were pioneers, and that the plans had been proved correct was the source of no small satisfaction.

The party, which entered the tunnel at 1.30 o'clock, came to the surface about 3.30 o'clock. The engineers stayed until much later and at 6 o'clock the bulkhead having been removed, the work of starting up the plant began. This is a delicate task, but it was accomplished quickly and successfully. The first to get the power was Buffalo. At a few minutes after 7 o'clock Niagara was running again, full tilt. The start made at 7 o'clock this morning will not be interrupted for a century.

On ground again, the heads of the party congratulated each other and had a lunch, prepared by the company. It was daylight.

All praised the masonry. It was beyond expectations, true and solid. Every one praised the engineering skill which had worked out the delicate problems so carefully.

Applications by the score had been received by the officials for permission to take the trip. Not one was granted.

APPENDIX J

THEORIES AS TO CAUSE OF DAMAGE TO TUNNEL LINING NIAGARA FALLS, AUGUST 5, 1908

A. H. VAN CLEVE, CONSULTING ENGINEER

THEORIES AS TO CAUSE OF DAMAGE TO TUNNEL LINING

NIAGARA FALLS, AUGUST 5, 1908

Even after the close inspection rendered possible by the erection of the scaffolding used in the repair work, the cause of the damage to the tunnel lining cannot be positively stated. New light, however, has been thrown on the subject and I am inclined to revise the opinions expressed on pages 5 and 6 of my report of June 16th. The three principal theories now advanced as to the initial and subsequent cause of damage are as follows:

1. The action of ice;
2. Stresses in the brick arch, alternately upward and downward;
3. A movement of the rock similar to that experienced in Wheel-pits Numbers One and Two.

The fact that the breaks in the tunnel lining occupy approximately the same relation to the ice shafts appears to be prima facie evidence that there is a relationship between the falling ice and the injury to the brickwork. It is to be observed, however, that while the greater damage to the brick lining occurs at a point from 20 to 70 feet from the ice shaft in the Wheel-pit Number Two, the damage in the vicinity of Wheel-pit Number One is from 60 to 120 feet from the ice shaft. As the velocity of the water in the tunnel was the same at both points and as the height from which the ice fell was approximately the same, it is difficult in ascribing to the ice the entire injury to explain this discrepancy. Further, it is strange that while the damage to the crown of the arch extends to the intersection of the tunnels, no cake of ice should have failed to impinge on the roof prior to meeting the water discharged from Wheel-pit Number One. In such a case it would have been driven against the side wall masonry with a violence much greater than that of its upward blow due to buoyancy. There is, however, no evidence of injury to the masonry in the side walls in front of the discharge from Wheel-pit Number One. A close examination of the brickwork shows fractures at the edges of the openings of such a character as would scarcely be expected from the action of an impinging body. That the action of the ice may have been a supplemental and contributory cause of the damage still appears to me to be probable, but that it was the origin of the breaks in the masonry bend does not seem so reasonable as it did after the more casual observation possible during the inspection of June 14th.

The theory of damage arising from stresses in the masonry lining caused by unbalanced pressures alternately upward and downward presupposed an existing break in the masonry bend of sufficient extent to allow the passage of air and water. It is based on the fact that in the original construction of the tunnel the space above the crown of the brick arch for a width of 18 feet was not a compact mass but was composed of stones driven between the lagging and brickwork. Between those stones existed air at atmospheric pressure. Furthermore, it is probable that this dry packing was not in all cases thoroughly tight, even though built with great care. When the water in the wheel-pits for any reason rose suddenly to a point some feet above the crown of the tunnel arch there would exist an upward pressure not balanced by the pressure above the arch until the water coming through the interstices of the brickwork established a condition of equilibrium, the entrained air being compressed with the same pressure as the water. If then the water level suddenly fell there would be a downward pressure due to the compression of said air above the tunnel arch, such pressure existing until it was lowered by the escape of water through the openings in the brickwork. There would thus be alternately a tendency to raise and lower the tunnel arch and to thus widen the openings in the brickwork. While the correctness of this theory cannot be gainsaid, the action above described presupposes breaks in the masonry lining. If for no other reason this is evident from the fact that practically the same pressures existed in the tunnel from Wheel-pit Number Two to a point considerably below the intersection of the discharge tunnels and over only a small portion of this length was any damage observed.

With a total length of tunnel of approximately 1⅓ miles, we find the masonry lining in substantially perfect condition (except for slight erosion), excepting at two points each having a length of about 50 feet. The material and workmanship employed at these points of localized damage were precisely that employed elsewhere, and no evidence of defects in either were observable. The brick was hard and the joints were well filled along the edges of the breaks. We must thus inevitably reach the conclusion that the damage was inflicted by localized forces not existing elsewhere in the tunnel. This conclusion led to the tentative adoption of the ice theory but, as stated above, there are phenomena not explainable on this premise. The manner in which the brick is shattered along the cracks indicates the action of forces greater than those heretofore considered. Moreover, there were cracks in the tunnel connected with Wheel-pit Number One and breaks in the joints of the granite intersection stones at points where ice could, by no stretch of the imagination, have impinged. In seeking for the primal cause of the difficulty, we must attempt to find a force of great magnitude whose action would naturally be confined to the points of rupture. We know that such a force moved inward the rock walls of both wheel-pits. The action of this force is now negligible, but it reached its maximum effect at the time Wheel-pit Number One was being extended and when Wheel-pit Number Two was being excavated. It is significant that the injury to the tunnel has in both instances occurred in the direct line of the wheel-pits and at points closely approximate thereto. Furthermore, it is evident that the brick lining was displaced some years ago. The rock movement in Wheel-pit Number Two attained its greatest magnitude during the time that blasting was in progress in that wheel-pit and the records show that the damaged tunnel arch near that wheel-pit was completed on October 3, 1901, while the blasting in wheel-pit did not cease until November 25, 1901. The tunnel lining at the point of rupture was thus in position at the time the compressive forces in Wheel-pit Number Two were actively at work as blasting was still in progress. We may safely consider the masonry bend in the tunnel near Wheel-pit Number One was probably broken prior to the inspection of May, 1902, as the rock walls of Wheel-pit Number One had reached a state of equilibrium prior to that time. I have been unable to obtain any evidence upon this point. The breaks recently discovered were in the immediate vicinity of the bulkhead which was being removed on the occasion of the inspection of 1902. The attention of all those in this vicinity at that time was naturally concentrated upon the removal of the bulkhead and as an inspection of the tunnel from Wheel-pit Number One to the portal revealed no evidence of injury, it is quite natural that a break in the crown of the arch near the bulkhead would have escaped attention with the light available at that point. It is also very probable that no brickwork had fallen at that time and the cracks would be difficult to discover.

The theory of the failure of the brickwork through rock pressure finds its strongest support in the following measurements made with great care at the several bents erected for the repair of the brickwork near Wheel-pit Number Two and at other points in the connecting tunnel. The same centers were used throughout the length of the tunnel in the original construction and changes in the tunnel dimensions cannot therefore be ascribed to a change of centers.

	Width at Spring Line		*Height above Spring Line*	
	feet	*inches*	*feet*	*inches*
Bent No. 2	18	$9\frac{1}{2}$	9	$6\frac{3}{16}$
3	18	10	9	$6\frac{3}{8}$
4	18	$9\frac{5}{8}$	9	6
5	18	$9\frac{1}{2}$	9	$6\frac{1}{4}$
6	18	$9\frac{1}{2}$	9	$5\frac{3}{4}$
7	18	$9\frac{1}{2}$	9	$5\frac{3}{4}$
8	18	$9\frac{3}{4}$		
9	18	9		
10	18	$8\frac{1}{4}$	9	$5\frac{3}{4}$
83 feet north of north face of lining wall of Wheel-pit Number Two	18	$9\frac{7}{8}$	9	5
35 feet north of bulkhead	18	$9\frac{13}{16}$	9	5
135 feet north of bulkhead	18	10	9	5
335 feet north of bulkhead	18	10	9	5
435 feet north of bulkhead	18	10	9	5

It will be observed from the above measurements that the tunnel lining in the vicinity of the break near Wheel-pit Number Two has been narrowed at the spring line and raised at the crown. I know of no force, except the rock movement, which would have produced this result. The evidence of compression is not clearly shown by evidence in the tunnel near Wheel-pit Number One, but it must be remembered that the breaks in the lining are of much smaller extent at this point than near Wheel-pit Number Two. Evidence of the forces at work does, however, exist in the cracks in the lining of the tunnel connecting Wheel-pit Number One with the main tunnel and in the breaking of the bend between the granite stones of the intersection. If the tunnel was squeezed laterally we would expect the joints to be wider on the extrados than on the intrados of the arch near the crown. This was clearly shown in at least one point near Wheel-pit Number One. After the bend was broken some force, due to ice, or to air or water pressure, or both, must have been exerted to have lifted the broken sections of brickwork, as they would otherwise naturally key themselves in position. One piece of brickwork weighing several hundred pounds was found wedged above its original position near Wheel-pit Number One showing that it had been violently acted upon in an upward direction. This lifting force was evidently of considerable magnitude.

It is natural to inquire whether we may expect a repetition of the injuries to the tunnel lining either at the same points or at other points, as the future usefulness of the tunnel will depend largely upon the answer to this question. If the damage was caused by the forces which move inwardly the rock walls of the wheel-pit, we may feel reasonably assured that further injury will not arise from this cause as the movement of the wheel-pit walls is now so insignificant. The age of the breaks in the tunnel makes it evident that the force which caused them was exerted years ago and there is no evidence of any progressive deterioration. That the destructive forces are not likely to affect the main portion of the tunnel is clearly shown by the excellent condition of that part below Wheel-pit Number One. On the other hand, if the action of the ice be accepted as the primary cause of the difficulty, we know that the existing and future conditions are not such as to render a repetition of this action possible.

The theory of injury through alternately upward and downward pressures exerted against the tunnel lining would be in itself an alarming one if it did not promise a primary injury to the lining from some other cause. That it is not in itself sufficient to destroy the lining is clearly evidenced, and now that the damaged portion of the lining has been restored to a condition more substantial than that which originally existed, it would seem reasonable to expect no future deterioration from this cause.

I believe, therefore, that as the destructive forces have now ceased to act, we may have a comfortable assurance as to the future stability of the tunnel.

A. H. Van Cleve,
Consulting Engineer.

Niagara Falls
August 8, 1908

APPENDIX K

FREEDOM OF CUSTOM DUES ON ELECTRIC CURRENT TRANSMITTED ACROSS THE INTERNATIONAL BORDER

FREEDOM OF CUSTOM DUES ON ELECTRIC CURRENT TRANSMITTED ACROSS THE INTERNATIONAL BORDER

The international connection established by cables on the Suspension Bridge across Niagara River, for the transmission of electricity between Power-houses Numbers One and Two on the American side and the power-house on the Canadian side, was facilitated by the ruling of the United States Treasury Department, June 20, 1890, "that electricity brought by wire from a foreign contiguous territory into the United States could not be assessed with duty, it being an invisible, subtle agent or power, and possessing no substance as a merchantable commodity."

This ruling was also useful for the Buffalo transmission, as it favored the construction of a Canadian as well as New York State line, thereby enabling the company to assure the continuity of power transmission by the use of a double line from the power-houses at the falls, one on each side of the river to Buffalo.

The Canadian authorities also facilitated the generation of electricity in the Canadian plant of The Niagara Falls Power Company for transmission to Buffalo, either directly on a Canadian pole line to a point in Canada opposite Black Rock near the Buffalo line, or by entering the United States over the Niagara Bridge for transmission on the American line to the receiving station in Buffalo.

During the year 1907 the Dominion Parliament of Canada enacted a statute, known as the "Electricity and Fluid Exportation Act,"[1] under the provisions of which the Dominion Government has issued to the Canadian Niagara Power Company a license to sell for export from Canada electrical energy at a rate not to exceed 60,000 horsepower.

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[1] See Amendment of March 16, 1925, given in Chapter XI, page 230, Volume I.

APPENDIX L

COL. THEODORE TURRETTINI APPOINTED FOREIGN CONSULTING ENGINEER

MARCH 10, 1891

COL. THEODORE TURRETTINI APPOINTED FOREIGN CONSULTING ENGINEER

MARCH 10, 1891

Theodore Turrettini of Geneva, Switzerland, served as Consulting Engineer in the development of the water-power at Niagara. In this connection an account of his brilliant engineering career is given, indicating his participation in the rapid transformation of mechanical processes from 1870 to 1900, and showing the part he played as a pioneer in various fields of science.

Born at Geneva in 1845, he belonged to an old family of Italian origin, which had established itself at Geneva in the period of the Reformation. A long line of ancestors (Magistrates, Ministers and Professors) had already brought fame to this family.

Turrettini had pursued his classical studies in the college of his native city, had entered the technical faculty of the University of Lausanne, where he was graduated in 1867 with the engineering diploma.

Before taking the direction of the Société Genevoise d'Instruments de Physique, a small company founded by some scientists, he went to Berlin to perfect himself as a mechanician, first with Bonsack, then with Siemens & Halske. He returned to Geneva and took the direction of the organization on the first of January, 1870.

This company employed at that time ten workmen and came out of every undertaking with a loss.

In the same year he married Mademoiselle Favre, daughter of Alphonse Favre, the professor of geology.

From 1870 to 1890 he worked upon the development of this company, which he put upon a solid foundation, and which attained a universal renown. From 1870 to 1874 very little was undertaken except scientific instruments. In 1874 he manufactured air compressors of high pressure, and pneumatic drills for driving the Gothard tunnel, in which he took a keen interest.

In this same year he constructed the first refrigerating machine, operating with sulphuric anhydride, invented by Raoul Pictet. This manufacture gave a great impetus to the development of the factory. The construction of the Equatorial of Bâle, and of an equatorial for Paris, contributed to the reputation of the factory.

He took an active interest in the inventions of Edison, and in 1880 spent six months at Menlo Park to work in collaboration with him.

Returning to Europe, he worked upon the development of electric lighting with the incandescent lamp until his activity was absorbed by the hydraulic works of the city of Geneva.

He was called by a popular vote to take a seat in the Administrative Council of the City of Geneva in order to solve three questions, viz; the regulation of the level of Lake Leman, the distribution of water in Geneva, and the distribution of water-power.

At the same time that Turrettini was directing his hydraulic works for the city of Geneva, he had numerous other works of importance under his supervision.

In 1891 he visited the United States as consulting engineer for The Cataract Construction Company, at Niagara, pursuant to the following invitation:

"Col. Th. Turrettini, "March 10th, 1891.
Geneva.

"Dear Sir:

"We have much satisfaction in confirming our exchange of telegraphic communications, as per copies enclosed, by virtue of which you have accepted our appointment as Foreign Consulting Engineer.

"We have been prompted to make this appointment by reason of the intelligent manner in which you have performed your duties upon the International Niagara Commission; by the interest you have manifested in our enterprise; by the high estimate we have formed of your practical engineering talent; and by our desire to have a member of our Engineering Staff residing abroad, who can properly represent our Company and keep us advised as to the progressive developments, in Europe, of the arts applicable to our business.

"We shall look to you to keep us informed regarding all matters of importance to our interests, connected with the construction and operation of our works. We have submitted the requirements of our proposed users of power to our Board of Engineers, which is now engaged in formulating definite plans for the development and transmission of the power required therefor. We have urged as much haste as possible in the preparation of these plans, which we desire you to carefully examine here with this Board of Engineers before they are finally adopted. We hope to be able to advise you early in April, when such progress will have been made as to make it profitable for you to come here. We desire that you should become familiar with the American practise in hydraulic matters, now established at such places as Holyoke, Lawrence, Lowell, Manchester, etc., and to visit Niagara Falls, making a careful inspection of the territory and becoming familiar with our plans for its development, as well as with the requirements of the lessees of land and power now about contracting therefor.

"We shall be pleased to have you make known the fact of your appointment, in order that you may be recognized in the scientific world, as our sole foreign representative in technical matters, and so that any communications regarding our enterprise, its development and utilization, may be directed to you for such attention as in your judgment they may require. We shall expect to keep you informed regarding our general progress; and upon such special points in regard to which, after your visit here, you may request particular information.

"We avail of this opportunity to express our appreciation of the kind offer you made on behalf of the city of Geneva, to permit the use of its power for the testing of any turbines that we might wish to submit to such trials in your country.

"Awaiting the confirmation of your communications by cable and an indication as to the period when it will be most convenient for you to be absent from home, we beg to remain,

"Very respectfully yours,
"The Cataract Construction Company
"EDWARD D. ADAMS,
"*President.*"

He returned for a second visit in 1893, a decisive year for the cataract company, for on that last visit the choice of the form of electric current was made.

APPENDIX M

B. G. LAMME, EARLY WORK ON FIRST 5000 HORSE-POWER ALTERNATORS

Description of Original 5000 Horse-power Alternators

EARLY WORK ON FIRST 5000 HORSE-POWER ALTERNATORS

B. G. LAMME

(This statement was prepared at the request of Mr. Adams made at the close of the ceremony of presentation of the Edison Gold Medal to Mr. Lamme in 1918 for "invention and development of electrical machinery."

The following description of the early work on the first 5000 horse-power alternators was written in the fall of 1920 by B. G. Lamme, the electrical designer of these notable machines. It throws an interesting light on an important step in the history of Niagara power by indicating the state of the art of dynamo design at that time and showing how many of the difficult problems were solved. Mr. Lamme prefaced his statement by saying that "Most of the material which I have given is based largely on my own connection with the work and my direct connection with others who were concerned with it; consequently, it is practically first hand information and agrees quite well with the records available in our engineering department."

The preceding electrical chapters have given an account of the generator designed by Professor Forbes, consulting engineer of The Cataract Construction Company, which was submitted to the Westinghouse Company in the summer of 1893, with the request that it propose such changes as might be found expedient in order to guarantee successful performance. Mr. Lamme's history of the design of the early alternators points out the salient features of the design by Professor Forbes and the reasons for the changes which were developed by the Westinghouse Company.)

The original design of Professor Forbes is quite interesting, from the present viewpoint, especially in indicating the serious mistake which would have been made if it had been adopted as it stood. It included many features which were then suspected, and are now known, to be utterly impracticable. It was on account of these doubts that the Westinghouse engineers objected seriously to the original design, and, in consequence, proposed alternative ones. The design finally adopted was a compromise between those of the Westinghouse Company and of Professor Forbes, embodying what appeared to be the most satisfactory features of both.

It might be of interest to review some of the features of the first proposed type as submitted to the Westinghouse Company. I have rather complete data on this machine which were jotted down many years ago in one of my note books. I have contemplated sometime making an analysis of the electric and magnetic characteristics of this machine for the purpose of publication, partly as an engineering curiosity, and partly to illustrate the limited knowledge of electrical machinery in those times.

This original machine fixed the general type adopted for the ten generators actually built. It was a vertical shaft type, with a rotating external field of the "umbrella" type, with the poles carried inside the field ring or yoke and with a stationary armature inside the poles. Thus far this general construction was adopted in the later machines; here, however, the real resemblance ends. In the proposed design there were eight poles, and as the machine was to operate at 250 revolutions per minute, this would give a frequency of 2000 alternations per minute (or 16⅔ cycles, in modern expression). The choice of this extremely low frequency was evidently based upon Professor Forbes' recommendations and was apparently predicated to a considerable extent upon his proposal to use alternating current commutating type motors, which he considered practicable at this low speed. It must be borne in mind that the polyphase induction motor (the Tesla motor) had not yet been developed to a commercial point and it was felt that any electric power scheme like the proposed Niagara development must use motors to a very considerable extent. Therefore, the problem of frequency was made subservient to the practical operation of motors and Professor Forbes considered the commutating type alternating-current motor as a solution of the problem.

FREQUENCY

Meanwhile, the Westinghouse Company had been working on a low frequency polyphase system with a view to operating rotary converters and induction motors. The early experiments had been carried on at practically 3600 alternations per minute (30 cycles). A working rotary had been tested and also induction motors had been experimented with and looked quite promising. In consequence, the company was contemplating putting out this low frequency quite independently of the Niagara Falls work.

As soon as the cataract company put its problem up to the Westinghouse Company, there was a clash of opinions. The Westinghouse Company was strongly in favor of induction motors, and rotary converters for converting to direct current, for general purposes in preference to alternating current commutator type motors. From the Westinghouse Company's viewpoint, 2000 alternations per minute was entirely too low for rotary converter or induction motor work, as possible range of speed combinations in the rotaries and induction motors would be extremely limited at this low frequency. In consequence, as an alternative, the company's engineers proposed a sixteen-pole generator at 250 revolutions per minute, giving 4000 alternations per minute (33⅓ cycles per second). This was so close to the 30-cycle work that had already been undertaken that it was considered a permissible departure.

In presenting the Westinghouse Company's case, some very interesting arguments were put up, as certain old records show. For instance, the possible speed combinations for 2000 and 4000 alternations, for both induction motors and rotary converters, were brought out quite fully and it was shown clearly that the higher frequency was far better. As neither the rotary converter nor the induction motor had yet been brought to the commercial point, this indicates that the practical possibilities of such apparatus were fully appreciated even at that early date.

For a time there was more or less of a deadlock on the question of frequency. The Westinghouse Company prepared designs for a sixteen pole generator, to show that such a machine was practicable and it also stated that in many features the Forbes' machine would not prove satisfactory and it took the stand that it did not wish to build such a machine, due to the great probability of complete failure from the operative standpoint. I do not know how the matter came up, but eventually it was suggested that, retaining the proposed speed of 250 revolutions per minute, a twelve-pole machine, giving 3000 alternations (25 cycles) might be a good compromise, and I was asked to take up the design to see whether such a machine was practicable. It soon developed that, from the standpoint of design and operation, such machine appeared to be quite superior to the proposed eight-pole construction and practically as good as the sixteen-pole we had already proposed. The question of the effects of this frequency on rotary converter and induction motor speeds was also considered and it soon began to look as if this compromise might be an excellent one. Eventually all opposition was overcome and the twelve-pole machine was adopted. The Westinghouse Company was given the contract for three of these machines and I was authorized to begin work on the electrical design of such a machine, utilizing the general type which had been proposed, but I was allowed to make certain quite important changes in details as will be mentioned below.

VOLTAGE AND REGULATION

The original eight-pole machines proposed were radical in many respects other than the frequency. They were designed for two-phase *20,000 volts*, with the intention of using this voltage directly for transmission purposes without the interposition of transformers. It was the use of this enormously high voltage, together with the design and construction features incidental to it, that raised the greatest protests from the Westinghouse engineers. The type of armature coils proposed, the number and arrangement of the coils, the huge open armature slots required, the method of dissipating the heat from these coils, the insulating arrangements, etc., were all subjected to severe attack. For instance, the original design of the two-phase machine had eight armature coils per phase or one coil per pole (see the accompanying figure). Each complete armature coil occupied two slots in the periphery of the armature. Thus with eight coils per phase, or sixteen coils total, there were only thirty-two slots total in the armature. The armature coils were approximately four inches wide and four inches deep. Each coil consisted of 110 turns of No. 2 B. & S. gauge, round cotton covered wire, and, if I remember correctly, the completed coil was insulated on the outside with ¼-inch thickness of "woodite," a new insulating material which apparently could be moulded into shape.

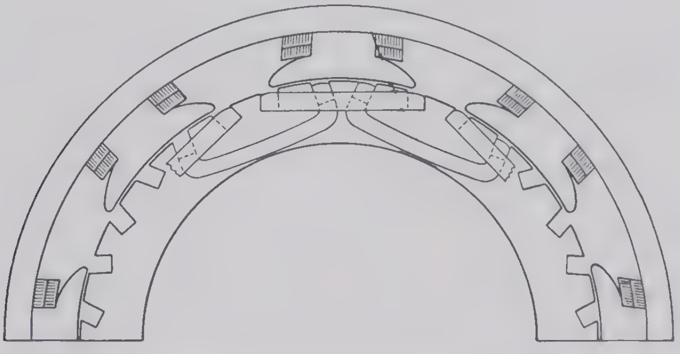

Diagram of Two-phase Machine Having Eight Armature Coils per Phase or One Coil per Pole

As these huge coils would be very liable to overheat, provision was made for cooling them by means of oil under pressure, which was to be forced into each coil at one end and was to flow in the interstices between conductors to the opposite end of the coil where it was carried off. It was argued by the Westinghouse engineers that such a method of cooling would be most unsatisfactory and unreliable. Eventually, to settle the argument, Dr. Sellers undertook to calculate the pressure required to force the required amount of oil through the coils, and the conclusion he finally reached was that it required about 400 pounds per square inch, which he considered impracticable.

Moreover, the proposal to generate 20,000 volts in the machine itself met with severe opposition and it was suggested that the use of relatively low voltage with step-up transformers was much more reliable. This opinion prevailed in the end, so that in authorizing the construction of these machines at the compromise frequency of 3000 alternations, a voltage of 2200 to 2400 was adopted.

Also the subjects of reactance and armature demagnetization, etc., were not so well understood at that time as at present, yet enough was known to indicate that the relatively small number of armature coils in the original machine, and the high armature magnetomotive force, would result in enormous flux distortions, very poor regulation, etc. Based upon these conclusions, the Westinghouse Company recommended "distributed" armature windings on these machines, the windings to be placed in a large number of slots per pole with only two conductors per slot, and this feature was used on the first three machines as actually constructed. In consequence, the first Niagara generators were constructed for relatively low voltage and with a relatively large number of armature slots per pole, this latter feature being comparatively new in alternator construction at that time. However, we had already obtained enough data with distributed armature windings to indicate that the reactance with such windings was relatively low and that this would probably be the coming type for all large work. Time had proved the correctness of this opinion. As the electrical design of these machines was placed in my hands, with Mr. Albert Schmid looking after the mechanical end in conjunction with the electrical, most of the new electrical features incorporated in these first machines were probably due to my own suggestions. However, it must be said that no radically new feature was adopted without consultation with all the parties directly interested in these machines and there was virtually full agreement throughout.

In recent years I have roughly reviewed the design as originally presented to the Westinghouse Company, with a view to determining, by present methods of calculation, the probable operating characteristics of this machine. The figures indicate that the machine was even worse than we believed at that time. From the insulation standpoint, this early design was apparently totally inadequate, based on more modern experience, and there is no doubt in my mind, but that it would have been necessary, after the machine had been put in operation, to have reconnected the armature windings in parallel for relatively low voltage, with the addition of step-up transformers for obtaining 20,000 volts. Moreover, from the heating standpoint, the machine was also totally inadequate, for unless the proposed oil-cooling system was almost theoretically perfect, there would have been excessive heating in the armature coils. According to my figures, the total dissipating surface on the armature coils was only one-tenth that of modern practise. Without oil cooling, the temperature attained at the rated current capacity would probably have been in the neighborhood of 300 to 500 degrees Centigrade. This, with the type of insulation used, would have been utterly impossible. Even with oil circulation, an almost ideal distribution of the oil would have been necessary to have prevented excessive local heating.

From the standpoint of armature reaction and reactance, this machine was excessively bad, according to modern methods of figuring. The full load armature magnetomotive force was about three times as great as the no-load field magnetomotive, an inoperative condition from the modern standpoint. Even with modern turbo-generators, under the most extreme conditions of the design, an actual armature magnetomotive force of one and one-half times as great as the field is considered rather excessive and, in some cases, dangerous, from the standpoint of parallel operation. Obviously, therefore, these early Niagara generators would have been extremely bad in this regard.

Also the armature reactance for these machines, as later calculated, would have been excessively high, far higher than anything represented by the most extreme practise of the present time.

The polar construction of the field was such that with the abnormal armature magnetomotive force, size of slots, etc., the flux distortion and pole saturation, etc., would have been excessive and, in fact, would probably have rendered the machine inoperative.

Also, according to my figures, the field winding proposed for this early machine would have been totally inadequate even at very high power-factor loads, in view of the fact of the enormous magnetomotive force of the armature relative to the field. In ordinary commercial service, apparently the field current would have had to be increased four hundred or five hundred per cent from no-load to full-load.

MICA INSULATION IN FIRST ALTERNATORS

I am bringing out the above points simply to indicate some of the features which we had to modify radically in the machines as actually built. As already stated, we distributed the armature winding in a large number of slots, using only two conductors per slot. By this means, our heat dissipating surfaces of the coils were enormously increased, and the problem of insulating the armature coils came within the range of existing experience. Even at that, fearing unknown conditions of temperature, we undertook a new thing in the matter of insulation, namely, the use of almost solid mica wrappers for insulating the parts of the armature conductors imbedded in the core. This was an expensive and difficult thing to do, but it was considered as in the nature of a most excellent insurance and well worth the price. Tests made within recent years, with thermocouples, to obtain the actual internal temperatures on these coils on the actual machines, have shown that instead of operating at the usual forty or fifty degrees rise, as indicated by thermometers on the exposed parts, the internal temperatures on the buried conductors have actually been as high as 225 degrees Centigrade for long periods and have averaged pretty close to 200 degrees Centigrade during the whole period that these machines had been operating, covering some twenty-five years. Furthermore, *this insulation is still in good condition.* The ordinary type of insulation, consisting of fibrous materials, in use when these machines were designed, would have broken down under these temperatures within a few months at least, so that when we adopted mica insulation on these machines, as a departure from the standard practise, we builded much better than we really knew.

Also in the construction of the actual machines, we went into the subject of ventilation quite carefully and figured out everything according to the best data available at the time. Considerable care was taken to ventilate the armature windings and the armature core was provided with numerous ventilating passages which was a construction just coming into use at that time. Such passages, however, were also shown in the original design. Even with the good ventilation provided, we missed it badly in the temperature of the buried armature conductors, as indicated by the thermo-couple readings mentioned above, but this was due almost entirely to the enormous eddy current losses in the solid armature conductors used in those days. There were no data or means at hand for calculating such eddy current losses at that time and all we could do was to "pile in copper" with a view to working at such low current density that the total losses would be within permissible limits. There was no way, in those days, to determine temperatures, except by thermometer, and it was impossible to place thermometers except on the exposed open parts of the winding. In consequence, reliable data regarding the actual hottest part of the windings was not obtainable at that time, nor for many years after.

So much for the insulation and the heating of the armature. In the machine as designed, provision was made for a relatively high field magnetomotive force, the field winding being purposely made considerably stronger than the armature, compared with one-third as strong in the original design. This was accomplished by the use of a "weaker" armature, a larger air gap and a greater number of field windings. The amount of field copper in the machine as built was quite large as compared with the originally proposed design. Notwithstanding this, the field coils in these first machines "roasted out" within a year or so after being put in operation and new strap wound field coils were designed of heavy section, with mica insulation, and with ventilating spaces between layers. These newer coils proved adequate and are in operative condition today.

Thus in the three fundamental features of heating, insulation and regulation, the 25-cycle machine, as built, was vastly different from the original design, and the proof of the adequacy of the substitute design is found in the fact that these machines have operated successfully for some twenty-five years.

VENTILATION

One of the troublesome features which developed in the tests of the first machine built was the ventilation. Means had been provided for drawing the air through the armature field along certain paths. A "blower," consisting of metal "scoops" on the upper frame or "driver" of the machine, was supposed to force air down through the machine along certain paths. However, upon test, it was found that these scoops were actually opposing the natural course of the air as set up by the rotation of the machine itself, and, therefore, dead air pockets were found in the machine. As soon as this was proved the suggestion was made that the scoops be reversed so that instead of blowing air into the machine they served to create a vacuum and pull it out. This enormously improved the ventilation, and, with other minor changes, we were able to get the desired ventilation.

The machine as a whole was of such a design as to set up an enormous air circulation and the problem was to utilize this circulation most effectively. Presumably this was one of the first instances where is was necessary to make a fairly definite study of the problem of air circulation in large electrical machinery.

25 CYCLES A STANDARD FREQUENCY

This first Niagara generator also initiated the 25-cycle frequency. The manufacturing companies had been considering the selection of some much lower frequency than 60 cycles, to be used with rotary converters in particular. Moreover, engine-type generators were coming into use and in those days many of the engines were of relatively low speeds, such as 75 to 90 revolutions per minute. Such low speeds did not adapt themselves well to 60-cycle alternators, due to the very large number of poles required. A 75 revolutions per minute, 60-cycle alternator, for instance, would necessitate ninety-six poles, and even 90 revolutions per minute would mean 80 poles. In consequence, some much lower frequency was considered desirable for engine-type generators, and when it became known that the Niagara machines would be built for 25 cycles, this seemed to offer a good solution for the slow speed engine-type alternator. In consequence, this frequency was very quickly adopted for engine-type work and I believe a few engine-type alternators were actually built and put in operation by the manufacturing companies before the Niagara generators were put in commercial service. However, the full credit for initiating this frequency must lie with the Niagara generators.

NEW METHOD OF DESIGN

From the Westinghouse standpoint, another important development resulted. Up to the time of the design of these first machines, the company's engineers had methods for calculating such machinery, more or less according to empirical methods; but from the design of the Niagara generators arose the present complete method of calculation, which has been used by the Westinghouse engineers ever since. This method started in a most interesting manner. Mr. C. F. Scott had a sheet iron templet cut out corresponding to the cross-section of one of the field poles. This in conjunction with an armature segment and paraffined paper, with iron filings, was used by him to make a "picture" of the magnetic field between the armature and the field poles of the machine. This was not uncommon practise in those days and was considered interesting and possibly instructive. Mr. Scott showed the picture to me and, after studying it a little while, I stated that I believed I could plot the flux conditions by calculation, just about as well as shown in this picture or possibly even better. Previous to this I had been attempting such plotting of magnetic fields on some large direct-current machines, so I undertook to plot the flux distribution of the Niagara field by calculation. From my plotted results, I then undertook to study the electromotive force conditions. It was obvious to me, even at that early time, that the plotted flux distribution or field form, corresponded to the electromotive force wave for one armature conductor. Also it followed that each armature conductor generated such an electromotive force wave, but displaced from the electromotive force wave of other conductors by an amount corresponding to the displacement of the armature conductors themselves. From the original flux distribution, therefore, I plotted the electromotive force waves of all the conductors of the winding in their relative positions, and then combined them to get the resultant electromotive force wave of the machine. This was done long before the first machine was completed.

MEASUREMENT OF WAVE FORM

The proof of the accuracy of this method, of course, would be furnished by a determination, by actual test, of the electromotive force of the completed machine. This was a difficult thing to obtain in those days. However, when the machine was set up for test, I arranged to wind a small wire cable around the external cylindrical field frame, one end of this cable being attached to a small windlass which was to be turned at a slow uniform rate to unwind the cable from the field and thus rotate the machine very slowly. The field was magnetized and a direct-current voltmeter was connected across the terminals of the armature winding with a view to taking direct readings at uniform intervals of time during the rotation of the frame. It was assumed that if the rotation was slow enough, the voltmeter needle would indicate in succession all the points in the electromotive force wave, and that an observer, by taking a large number of these readings, at regular frequent intervals, could thus plot the electromotive force wave of the machine. This was done, in a number of tests, and the interesting fact is that these readings all checked very closely with each other and, moreover, *the measured electromotive force wave of the machine coincided almost exactly with the one predetermined by calculation, as above described.* It was evident that here were the elements of a method of calculation based upon actual flux distributions in the machine itself. Taking this as a basis, I worked on the method, during my evenings, for the next two or three years, expanding it and applying it to various kinds of machines, such as direct-current machines, alternators, induction motors, rotary converters, etc., and checking by actual test on various machines as they came through the shop, until I had proved that the method was fundamentally correct and was applicable, in general, to all our rotating apparatus. This developed method is the basis of the company's calculation systems of today. While this system probably would have been developed later through other channels, yet it must be said that it was given its principal incentive through the first Niagara generator.

CONSTRUCTION AND BALANCING

In the actual shop construction of the first Niagara machine, many new problems came up which had never been encountered before. The building of large slotted armatures, with segmental punchings brought out many new constructive and manufacturing difficulties. Even the filing of the armature slots of these big machines presented many new problems. Mr. Albert Schmid, then shop superintendent, who also had charge of the drafting-room, and was responsible in general for the mechanical features of the machine, together with myself, who handled the electrical design, were in almost continual discussion of new manufacturing features and difficulties which were coming up every day. Lots of changes had to be made, due to manufacturing limitations. A large number of little things had to be watched, each of which, in itself, was of very minor importance, but which in the aggregate might be serious. However, when it came to the running tests, at first we were up against a real problem, for we did not have very good shop facilities for testing such machines, especially as they were of the vertical shaft type. The balancing of these machines also presented a serious problem. We had to rig up a special driving motor in a pit below the machine, for running the machine up to full speed. The field supporting housing or "driver," as it was called, was suspended on a small hardened steel ball, and, through proper mechanism, was spun at a relatively high speed to determine the conditions of unbalance and to allow accurate balancing. According to the figures of a number of mechanical engineers, including Dr. Sellers, I believe, this ball was totally inadequate to carry the weight under those conditions, but nevertheless the test was made successfully. An interesting side incident in connection with this was that the company, which furnished the steel ball for this test, assumed, without proper grounds, that this was going to be one of the standard requirements of the Westinghouse Company and, consequently, sometime afterwards they wrote asking when we would require more of these balls, as they had prepared a stock of *five thousand.*

ELECTRICAL TESTS

In the testing of the first machine we wished to obtain saturation curves and other data and yet did not wish to install the final armature winding as we did not think it safe to ship the armature complete with the windings in place. In consequence, the full winding was put on, in a temporary manner, that is, the slot conductors were put in place and the strap end connectors were attached to them by means of small steel bolts without solder and no tape was used over the joints. The machine was put on test and apparently ran in a satisfactory manner. An observer climbed up inside the stationary armature spider to observe the ventilating conditions, etc., while my associates and myself undertook to obtain the saturation curve of the machine by exciting the field. Readings were obtained at different field strengths up to practically normal voltage and then suddenly something happened. It developed afterwards that some of the little steel bolts, which clamped the strap end connectors to the slot conductors, had loosened up under vibration and finally shook into contact with each other, thus forming a short circuit between two or more conductors at the end of the core. This started an arc and the draft of the machine immediately carried this to adjacent end conductors, all of them being untaped, and, in a moment, there was one tremendous arc around the end windings of the entire machine. The tremendous air blast forced the arc in all directions, even down inside the internal spider and far out below the lower edge of the rotating field frame. It looked, at first glance, as though the whole infernal regions had broken loose. Everybody jumped for cover, as we did not know what was going to let go. The principal tester (E. R. Hill, now of Gibbs & Hill), on his way toward shelter, reached out and grabbed the rheostat handle and whirled in all the resistance, while on the run, and this "killed" the machine so that the arc died down very quickly. This I believe, was the first heavy short circuit in an electric machine that any of us ever saw. In a few seconds after the trouble was over, we all came back to the machine and some one climbed underneath to see what had become of our man inside the spider, expecting him to be badly scorched. However, he sat there crouched up close to the shaft, but without injury of any sort. He said that the fire came in all around him but did not touch him.

SHORT CIRCUIT TEST

As soon as the cause of this trouble was discovered, the connections were all bolted up and soldered and taped sufficiently to prevent a repetition of the short circuit, and other tests were made. One of the tests made was to short circuit the machine on itself and gradually build up the field charge to normal value, to determine how much current would flow on short circuit. If I remember rightly, the machine gave about two times full load current on steady short circuit conditions, and there was no particular vibration or disturbance of any sort under this condition. However, I then told the testers to bring the machine up to full voltage and then "dead short circuit" it at the terminals, naturally expecting the machine to give about two times full load current. However, there was a terrific shock and the end windings showed evidence of being disturbed and flakes of mica came off the slot conductors, as if they had been hit a tremendous blow. This was the first time I had ever seen a large machine dead short circuited on itself and this was the first real knowledge that I had that the momentary short-circuit current in an alternator was enormously larger than the steady short circuit. My explanation of this, at the time, was that the momentary short-circuit current was limited only by the armature reactance, or "self induction" as we called it at that time, while the steady short-circuit current was limited by the demagnetizing effect of the armature on the field. I suggested that during the instant of short circuit, the armature had not yet had time to demagnetize the field and, therefore, an enormous current resulted. The interesting part about this is that this action was not thoroughly investigated or analyzed until many years later, when we began to get in trouble from instantaneous short-circuit current rushes on large turbo-generators. Here were the indications of certain important phenomena, which, however, were not fully appreciated. Sometime after the machines were installed, short circuits were encountered at Niagara Falls which distorted the end windings of these machines and it was found necessary to modify the supports of the windings. If we had fully realized the possibilities of danger in this first shop test, we could have saved ourselves trouble later.

ROTARY CONVERTER CONTROVERSY

As a side issue to this generator development, I may mention one important incident which occurred in connection with rotary converters. At that time I was carrying on a series of tests on an experimental rotary converter, consisting of a direct-current railway generator with collector rings added. Numerous tests had been made to show its ability to convert from alternating to direct current. The machine was then shown to visitors from Niagara, including Professor Forbes and Professor Rowland. Professor Forbes incidentally remarked that he believed the loss in this machine as a converter was the difference between the losses as an alternating-current machine and as a direct-current machine. Professor Rowland almost invariably took the opposite side from Professor Forbes and immediately stated that it was the sum of the losses instead of the difference. Then the argument was on. Neither side would yield and neither had any actual data on which to base an argument. Considering that this was a most interesting and valuable point, and not feeling capable of taking part in the discussion by such eminent authorities, I quietly gave instructions to have tests made to find what were the facts regarding its comparative rating as a converter and direct-current generator. It so happened that in this machine there was a very definite load limit as a direct-current generator, for it had been proved by many tests that with a certain current for about four hours, it would begin to smoke. Consequently, tests were run to find the corresponding current which would make it smoke when acting as a converter. The test showed that with 400 amperes load, about the same heating and smoking conditions were produced in the armature copper as obtained with 280 amperes as a direct-current generator. This was a most positive result, for it was known definitely that this machine could not possibly carry 400 amperes for any appreciable length of time as a straight direct-current generator. Therefore, unquestionably, the armature loss was less as a converter than as a direct-current generator. However, when the results of this tests were placed before the two electrical engineers of the cataract company it apparently had no effect, as one of them rejected the results and the other accepted them. However, the results were conclusive in showing that the rotary converter had smaller losses than the corresponding direct-current generator, and the knowledge of this result had considerably to do with pushing the development of the rotary converter. I mention this simply because it arose from a controversy in connection with the Niagara Falls work.

ADDITIONAL GENERATORS—RECONSTRUCTION

Several years after the completion of the first three generators for this plant, an additional order for seven machines was placed with the Westinghouse Company. These later machines were very similar in general design to the first three, the principal modification being in the armature winding which was made with practically twice as many slots, and with one conductor per slot instead of two. The regulation characteristics on these newer machines were also slightly better than those of the first three. Otherwise the characteristics were very much the same.[1]

As a part of this little story it may be mentioned that within the last few weeks, a contract has been placed with the Westinghouse Company for the reconstruction of the first three machines and two of the later ones, to change them to 12,000 volts instead of 2400, to conform with the standard practise on the modern types of generators used by this company. Thus, after some twenty-five years, these machines will be brought more nearly in line with modern practise. It may thus be said that the commercial life of these early machines was about twenty-five years, which is very long for electrical machinery, especially for new and radical types, such as these machines were at the time they were built. To illustrate one change in the times, it may be mentioned that the official of the Westinghouse Company who is in direct charge of manufacturing, knew nothing about this contract until about two weeks after it was taken, and he did not even know that the company had been asked to take up this reconstruction. In other words, on account of the enormous growth of the manufacturing business, the reconstruction of these five 3750-kilowatt machines hardly created a ripple on the manufacturing surface, whereas twenty-five years ago they were the monsters among electrical machines. In view of the growth of the business, however, this is not surprising, for recently at Niagara Falls there have been installed three 32,500 kilovolt-ampere generators, that is, of almost ten times the capacity of the original Niagara machines. Moreover, hydraulically driven units of even larger size, up to 45,000 kilovolt-amperes are now being built.[2] Alongside these huge capacity machines, and the 30,000 to 40,000 kilowatt turbine-driven generators of modern practise, the reconstruction of five 3750-kilowatt machines does not attract any particular attention. Thus these early machines which, when first built, attracted universal attention, have become mere incidents of the business, in their reconstruction.

So much for these first generators; they led the way toward modern types of alternators in certain respects. They were of the rotating field construction, which is now universal, whereas the standard machines of that time had rotating armatures. But the type of field construction adopted on these early machines, namely, an external rotating field with internal stationary armature, did not persist, for various reasons. The later internal rotating field construction possessed advantages great enough to result in its superseding all others. The Niagara external field ring construction was very expensive in material, was difficult to manufacture, and did not tend toward natural ventilation, as is the case with an internal rotating element. In view of the fact that the limitations of copper and iron were approached long ago, and that our greatest modern advances have been through improved means of heat dissipation, we can realize that development has tended naturally toward that type which lends itself best to ventilation.

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[1] See "The Reconstruction of the Umbrella-type Generators at Niagara Falls," *The Electric Journal*, August, 1922.

[2] Within a few years after Mr. Lamme wrote this statement The Niagara Falls Power Company installed three 70,000 horse-power units.

However, these early Niagara machines were pace-makers, and, that they have been out-distanced eventually is no discredit to them; for, as stated before, they have served for twenty-five years, which makes them patriarchs in the electrical field.

PERSONNEL

We have dealt with the machines, and now for their makers. It is impossible to give individual credit to all who were interested in the early design of the first Niagara generators and electrical equipment. As already brought out, a number of important features in the first machines constructed were taken directly from the original design as presented by the cataract company. In the machines as built, many of the important features were gone over and reviewed by everybody concerned and so many suggestions were made here and there, that most of the ideas embodied in the machine were, to a certain extent, the resultant of the opinions of several persons. Consequently, it would not be right to refer to any individual engineer as responsible for these machines. There were no older engineers on this work, with younger assistants, as is now common; for there were no "older" engineers then, all of us being in the younger class, all of us being young men, and young at the business, and the business itself was very young, from our present viewpoint. Everybody was optimistic and enthusiastic, willing to take long chances, especially as we hadn't sufficient data to show the dangers. True conservatism, fathered of expensive failure, was not yet born. But we were all good designers, according to the definition I once gave Mr. Schmid that "a good designer always left a way open to make a change in case of trouble or failure."

Many of the men actively interested in this early Niagara work are not with us now. George Westinghouse, Oliver B. Shallenberger and Albert Schmid have passed away; Stillwell, Scott, Wurts and many others have taken up other fields of endeavor. Of the few engineers still with the company, I recall at the moment only Mr. H. P. Davis, now vice-president, Mr. C. E. Skinner, now manager of the research department, Mr. Siegfried, mechanical assistant to Mr. Schmid, and myself. Mr. P. M. Lincoln, one of the company's young engineers who was selected to operate this plant at Niagara, and whose history is quite intimately tied up with this first generating plant, was, until quite recently, still with us.

In the early day, Mr. Stillwell had much to do with this undertaking, in the way of consulting work in general, dealings with the cataract company, and determining the general contract conditions. In other words, he was what we now would call the "general engineer" on the work. Mr. C. F. Scott acted in an advisory capacity in many ways. Mr. Skinner had much to do with the development of the mica insulation on both the armature and field of the generator. Many others, such as Mr. Lange, Mr. H. P. Davis, Mr. Wurts and Mr. Siegfried were in direct contact with the work in its various stages. Mr. Albert Schmid, as general superintendent, was largely responsible for the design as a whole, while, as intimated before, the electrical design of the generators was turned over to me, although I was in daily consultation with the other engineers on all important features. So, in reality, it must be considered that this equipment was the production of many men and not of any one individual. Thus this great undertaking, like all large engineering feats, was the result of the co-operation of many able and constructive minds.

October 20, 1920

* * *

CONSTRUCTION DATA OF ORIGINAL 5000 HORSE-POWER ALTERNATORS

The following are the principal structural data of the 5000 horse-power "umbrella type" alternators installed in Power-house Number One.

The forged nickel steel ring was 11 feet, 7⅛ inches external diameter, 4 7/16 inches thick and 4 feet, 2½ inches in height. The weight was 26,700 pounds. Inside the ring were bolted twelve cast steel pole pieces 15 inches wide and 30 inches long, each surrounded by a coil. The total weight of rotating parts was approximately 79,000 pounds. The fly-wheel effect of rotating parts was 2,020,000 foot pounds at one foot radius. The total weight of the generator was approximately 170,000 pounds.

The external rotating type of generator was adopted in order to secure a high fly-wheel effect without exceeding definite limitations of total weight and thus meet the conditions fixed by the designers of the hydraulic turbines and governors in order to meet the specifications regarding change in speed when there was a sudden change in load.

The diameter of the internal stationary armature was 104½ inches and the air gap was ¾ inches. There were 187 partially closed slots ⅝ inch wide and 3¼ inches deep. There were two bars per slot. The bars were insulated with a wrapper of Lonsdale cambric and mica; the thickness of the mica, including the cotton tape for binding the wrapper to the bar, was seven-hundredths of an inch. After three machines were built a change was made in subsequent machines to 322 slots with one bar per slot.

The field coils of the first three machines made in 1894 and 1895 were wound with copper strap .3 inch x .4 inch, cotton insulated. The coils were insulated from their enclosing brass bobbins by wood and the outside was covered with heavy cord. The ventilation was inadequate and they ran exceedingly hot. They were replaced by field coils of copper strap approximately ⅛ inch x 1 inch wound on edge. There were four such coils placed in concentric fashion and separated for ventilation by aluminum spacers insulated with mica and enclosed in a copper shell. The number of turns per coil was reduced from 192 to 189½. This type of field coil and the mica insulated armature bars were in excellent condition after twenty-five years of service. The machines were rated at 5000 horse-power at 2200 to 2400 volts, two-phase.

Drawings and illustrations of the machines will be found in Chapters XXII and XXIII, Volume Two.

APPENDIX N

C. E. L. BROWN OF BADEN, SWITZERLAND

Invitated to Establish Machine Works
at Niagara Falls, October 18, 1891

Paper on High Tension Read at Frankfort, February 9, 1891.

INVITATION TO ESTABLISH MACHINE WORKS AT NIAGARA FALLS, OCTOBER 18, 1891

C. E. L. Brown, Esq.
Baden, Switzerland

Dear Sir:

Not having heard of your establishing permanent since the severance of your connections with the Oerlikon Company, I beg to suggest to you the opportunity that now exists for a gentleman of your profession for the establishment at Niagara Falls of manufacturing enterprises with which you are somewhat familiar. The number of contracts that we have made and now have under negotiation, indicate very clearly that there will be a very rapid development at that place. The most favorable opportunity is that for the establishment of a machine shop. Primarily this would have its first large business in the construction of turbine wheels, and such additional machinery as it had the capacity to supply for the new manufactories in the process of construction. As this will become the great electrical center, all electrical machinery will of course be in great demand, and a manufactory of such articles upon the spot would, of course, have a superior advantage, if their work represented the highest state of the art, and not only in the supply of the original installation, but of their repair and extension.

There are three other opportunities that have not yet been formulated into business shape, all in connection with the use of a large amount of electricity:

First: for the smelting of copper mat. There is an enormous amount of this material shipped to Swansea, England, for treatment. The favorable location of Niagara Falls, in the highways of travel and cheap transportation, would give that locality great advantages, entirely irrespective of the cheapness of its power, which, of course, is a profit of itself in comparison with other localities.

Second: for the manufacture of aluminum. The two interests here (the Pittsburgh and the Lockport interests) are not prospering. There is a lack of capital; there is litigation, and the opportunities for the establishment of a great business are being wasted.

Third: there is the electrolytic treatment of salt in the manufacture of alkali. Some of the largest salt works in this country are located in the center of the State of New York, within a short distance of Niagara Falls.

There are other manufacturing interests in which cheap electricity in continuous supply affords new and profitable business opportunities.

Commending these subjects to your attention,

I am, with best wishes,
Very truly yours,
Edward D. Adams
President

As Mr. Brown had already contracted with others for the formation of Brown, Boveri & Company he was unable to consider the invitation in the foregoing letter.

HIGH TENSION ALTERNATING CURRENT PRODUCTION, TRANSMISSION AND USE OF THE SAME

Charles E. L. Brown, Electrical Director Maschinenfabrik Oerlikon

(Paper read at the annual meeting of
the Elektrotechnische Gesellschaft zu
Frankfurt a. M. February 9, 1891)

Most Esteemed Assemblage:

I have been honored by the Elektrotechnische Gesellschaft in being permitted to address you here today. Kindly do not expect too much of me. I, however, have something new and interesting to present to you.

I do not have to review for this assemblage the theoretical considerations, how a definite amount of energy passes along rather small conductors with small losses if their voltages are chosen large enough. The simplest calculation shows how we could transmit tremendous amounts of energy over very small wire to the most distant localities with a minimum loss were not practical limits placed on the magnitude of voltage.

Practical limits are presented, just as in other fields, which restrict us.

These limits are fixed by the following considerations:—

What maximum voltage can we safely generate for an industrial operation in an apparatus?

What maximum voltages are we in a position to transmit long distances with the means available?

And to what degree can we protect ourselves from the dangerous effects of a high voltage electric current?

Until the present time, voltages of 2000, 3000 and perhaps even 4000 volts were considered as the maximum to be used for practical operation. My intense activity in the field of electrical transmission however, as well as the continuously increasing sizes of projects whose execution under certain assumptions would assure a great national economic advantage and seems more and more a necessity, showed me that we are not very far away from the time when we shall fully harness electricity. My efforts, for a number of years, have been directed towards the introduction into practical operation of continuously increasing voltages, and consequently the question naturally arose as to "how may these be generated in the most rational way?"

If we examine our ordinary direct-current machine somewhat closer in regard to this question we very soon come to the limit of practical possibility.

The natural arrangement of its armature winding and the necessity of a commutator make rather difficult the construction of machines for quite high voltages, at least with the insulating materials at our disposal up to the present time.

I have built direct-current machines up to 2000 and 2500 volts which were capable of operating continuously day and night without any trouble. However, their design has shown me that high voltages in such a machine, even if they should be generated, will lead to proportions, especially between insulating material and the armature copper, which would give to the machine an uneconomic size.

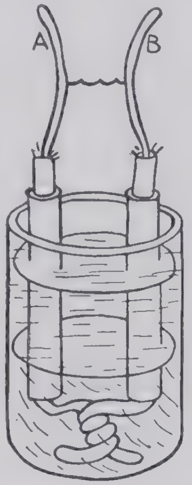
These proportions distribute themselves more favorably for an alternating-current machine, which is to deliver a high tension current. The individual, completely separable distribution of its armature winding, which generates only a fraction of a total voltage, the omission of the commutator, and eventual possibility of having the armature remain entirely stationary, and to set into rotation the magnetic field, make the alternating-current machine essentially better adapted for the generation of higher voltages. A very excellent example of this set are the large Ferranti machines.

The most ideal apparatus for our purpose is one which is absolutely stationary, does not require continuous attention and is finally so constructed as to be kept in continuous service, without interruptions, over long periods of time. The transformer with stationary windings for converting alternating-current from one voltage to another is such apparatus.

A transformer according to my opinion should be so designed that its constituent parts may be dissembled readily. It should possess primary and secondary windings which are independent of each other which may easily be removed from the core at any time. The coils should be of such design as to be easily wound with any lathe. The insulating material used for covering them should be placed as to prevent short-circuiting between the windings. Finally the whole apparatus and the external protective contrivances should be so chosen as to function continuously without danger under all conditions. Such apparatus has been manufactured by the Maschinenfabrik Oerlikon.

Because water which is absorbed in the insulating material used for the lower-voltage transformers of 2000-3000 volts leads to disastrous results, a new factor, oil, is being introduced as insulation for higher voltages—20,000, 30,000 and 40,000 volts. Oil is one of the best non-conductors and is capable of filling the pores of the various materials which are used for insulating purposes such as cotton, paper, etc., and also protects these against the elements.

For testing oil as in insulator the ends of two cotton covered wires are twisted together. This is inserted in a vessel filled with oil (see illustration) which is strongly heated for a rather long period of time in order to expel all moisture from both the cotton and oil. Over the wires are placed glass tubes. If the ends of the wires projecting into the air are connected with the poles of an influence machine, sparks several centimeters in length, may be generated between the portions of the wire projecting into the air without breakdown between the lower portions immersed in the oil. This is a good test for determining the insulating quality of oil.



The first use of oil for this purpose was probably made by Brooks in his underground transmission lines in which he used ordinary insulated wire which was drawn through a tube containing oil. I introduced the use of oil for use in high voltage transformers. My process consisted in immersing the apparatus in a cast-iron tank filled with oil and heating this for a rather long period of time above 150 degrees Centigrade. I was able to go up as high as 40,000 volts with this type of transformer, without any difficulty whatsoever.

We have now seen how by means of transformers we can reach exceedingly high voltages without difficulty. I will now outline briefly my views, in which I predict that all generating stations will be equipped with such apparatus.

The current-producing generator thus becomes an alternating-current machine whose voltage may be selected as low as possible, for by that means such a dynamo may be developed in the truest sense of the word. This remark will be more readily understood if I state that the windings of the armatures of the machines which are used for operating the machine works at Oerlikon consist of copper rods 30 millimeters thick which were inserted into paper tubes for insulation. It will perhaps surprise you to hear that the winding of a dynamo may consist of thick massive copper bars, the use of which is made possible by permitting these rods to rest in closed holes of the armature-iron, a design which as is known, I had used in 1885 in my ordinary direct-current machines. If you can picture such an armature with stationary copper rods resting in the armature-iron at about 40 volts, which in addition had no commutator you will readily agree with me that this machine had to satisfy extraordinary requirements for sure and safe operation.

The current of such a machine is then stepped up to a higher voltage by means of a transformer, the oil of which acts not only as a protection against moisture and dust but also as an absolute protection against touching with hand by the individual.

There only remains now to briefly describe the indicating instruments and the safety appliances used in the station.

All switching manipulations are made at rather low voltage. They therefore do not present any greater dangers than our normal low voltage direct-current plants.

A static volt-meter may be used as control for the high secondary voltage, which because of the absence of any coil, is an extremely simple and reliable apparatus and which since it is direct reading may easily be mounted so as to eliminate the chance of injury due to contact.

In addition the usual safety contrivances are necessary. Lead fuses serve against short-circuiting. In case of the breaking of a wire of a transmission line, minimum current circuit-breakers are used and the safeness against grounding is effected by means of static apparatus.

Let us now pass on to a discussion of long-distance power-transmission. The overhead transmission line is the only system which should be considered. I know that electricity will, in this connection, be subject to prejudices, but I am convinced that time and experience will overcome this. I am fully convinced through past experience that the overhead line may be so arranged that it shall correspond in every respect to the requirements which are placed upon other common types of construction work.

For supporting points of high tension transmission line double-bell telegraph insulators serve well in dry air. The insulating capacity is lowered with an increased moisture content of the air which makes possible the surface conduction of current.

Here again oil is called into play in the form of the well known Johnson & Philip's fluid insulators. These consist of a porcelain-bell, which has, on the lower edge toward the inside, a channel. This channel is filled with thin oil of lower specific gravity than water. If water falls upon this it does not spread in a continuous plane over the surface of the oil, but scatters as individual droplets, which if above a definite size, sink below the surface.

It should not be feared that the oil in the channel will be readily displaced by water, because it takes quite some time for an appreciable amount of water to deposit.

The above insulator is exceptionally efficient. Prof. H. F. Weber in Zurich tested such insulators which were in service for one and one-half years in the Kriegstelten-Solothurn transmission system with a current at 2000 volts and could not detect the slightest leakage.

Notwithstanding this, I do not consider these insulators satisfactory for transmission of power at ten times the voltage and have made suggestions for their improvement.

The most simple multiplication of the insulation consists in the superposition of insulators, i.e., two insulators one placed on top of the other. The same effect may be obtained with only one insulator if the middle portion of same is made of porcelain with three oil rings and upon which a glass-lined cast-iron cap is placed.

A further modification would be to place a porcelain-bell on a similar middle piece with oil rings which at times have a small channel as in the fluid insulators described above.

Such insulators should not be entirely neglected. They should be examined, from time to time, cleansed and refilled with fresh oil. This is a decided advantage since as a result of it an involuntary control is effected over the fastening of the wire to the insulator, the poles and other protective devices which otherwise would be neglected.

Poles will next be considered. The simplest type are wooden poles. Since we will under all conditions strive to lessen the number of points of support, we will therefore make these as strong as possible and set them about 70-100 meters apart.

When using high iron supports (steel towers), the distance between individual points of support will be about 200 meters, for which corresponding strong line material should be selected.

Under all circumstance the posts should have maximum heights and the transmission lines should be placed above telegraph and telephone lines.

Next to be considered are lightning arresters. These must be placed both at each end of the transmission line and, from time to time, upon the intervening stretches and must be so arranged that they automatically interrupt the resulting passage through lightning and the eventual leakage resulting therefrom of the line-current. This may be effected by having the lightning pass between two carbons which will automatically separate from each other during the current flow, extinguishing the existing arc after which they move together and are again ready to function.

Another item which must now be considered is current leakage into the air. The voltages at which this may be of importance will perhaps be learned within the near future as a result of experiment. The danger of this type of loss is much less than that which we have assumed up until now as most common in engineering.

I will now pass on to the use (application) of such current. The machines which will be considered will not be so much those which convert power given to it at one end into mechanical power, but will as a rule consist rather in distributing electric current for all purposes of motor drive, of illumination, etc.

Under no conditions, will the current be used at its high voltage, less so will it be directed to the consumer at such voltage.

The conditions will rather, in nearly all cases, so arrange themselves that the current before its use must not only be stepped down once but even twice in which the voltage, of 30,000 volts in transformer stations, is reduced to a voltage of 1000 or 2000 volts and at this voltage then the distribution to the customers or to transformers is affected.

This whole arrangement from the primary station to the use of the current may at first glance perhaps seem as an extremely unsatisfactory one with reference to efficiency and uneconomical in regard to maintenance cost.

A closer examination, however, leads to an entirely contrary result. First concerning the primary arrangement, dynamos for quite low voltages may be built at a lower cost than for high voltages which may compensate for the price of the primary transformer. In addition, the efficiency of the machines for lower voltages is greater than for machines for higher voltages so that in that respect also the difference for the combination of machine and transformer is an unimportant one amounting to only 1 or 2 per cent.

The chief results of the use of high voltages will be a saving in material necessary for transmission lines and the losses in same will be reduced to such an extent that the increase in cost for the transformers and the loss in the tranformation will be more than off-set. A simple example will prove this to you.

Let us assume that we have 500 horse-power to transmit 20 kilometers and wish in one case to generate a voltage of 5000 volts with a dynamo and in another case a voltage of 30,000 volts by means of transformers and work only with 3 per cent transmission line loss. In the first case, we will have to have a copper wire of about 90 square miles; the weight of the former being 32 tons and in the latter 3.2 tons. The additional cost of the transformers will be off-set by the saving in the transmission line cost.

Let us now consider this matter from an efficiency standpoint. The efficiency of a 500 horse-power generator at 5000 volts should have a maximum value of 92 per cent. If we add to this line losses which amount to 10 per cent, we obtain about 83 per cent at the end of the transmission line. In the second case the efficiency of the primary dynamo and transformer is 90 per cent, the efficiency of the line is 97 per cent and about the same for that of the secondary transformer. We thus obtain a resultant efficiency of 84 per cent. In addition to this, in the second case, we can deliver our 84 per cent at any voltage while in the first case at a voltage of 4500 volts which is not suitable under certain conditions and, therefore, has to be transformed still further.

It is self-evident, that the second case of the multiple transformation is essentially the more economical.

I should like to remark here that the idea, of stepping up and at the terminus of stepping down the voltage, is not new. In 1886, I proposed to the city of Naples a project based on this and was figuring at that time to go up to 10,000 volts in the transmission line. The time was not yet ripe for this, and consequently the project was not put through.

The special purpose which the plant is to serve will naturally determine what type of current system will be introduced. If it is a question only of driving a motor or for electric lighting, ordinarily alternating-current will suffice. If in addition to the electric illumination, it is desired to operate small motors, polyphase alternating-current offers the most diverse applications.

I have attempted above to outline how, according to my opinion, electric energy may be transmitted over long distances by using high voltages.

APPENDIX O

ENGINEERING EXPENSES
IN
EUROPE

MEMORANDUM OF ENGINEERING EXPENSES IN EUROPE

OF THE INTERNATIONAL NIAGARA COMMISSION AND INCIDENTAL THERETO, OF THE CATARACT CONSTRUCTION COMPANY, AND NOTES RESPECTING THE PARTICIPATION OF FOREIGN ENGINEERS AND MANUFACTURERS IN THE DESIGN AND CONSTRUCTION OF THE HYDRO-ELECTRIC EQUIPMENT OF THE POWER STATIONS OF THE NIAGARA FALLS POWER COMPANY

The payments made to foreign engineers during the years 1891–1893, including the expenses of the International Niagara Commission, amounted to $75,872.91; this did not include the salaries and expenses of several members of the American Board of Engineers and officers of The Cataract Construction Company attending the sessions of the International Niagara Commission and in connection therewith, nor any payments made to foreign manufacturers for their designs, construction and installation of machinery purchased from them. Additional payments were made after 1893, from time to time, for expert advice by foreign engineers.

The participation of foreign engineers in the development of the power plants of The Niagara Falls Power Company commenced with the appointment of the International Niagara Commission which began its activities at preliminary meetings held in London, England, in May, 1890. At these meetings a letter of invitation was prepared and sent to a chosen list of engineering constructors, inviting them to submit, in competition, plans for the development and distribution of power at Niagara Falls. A report on the projects submitted to the International Niagara Commission was prepared under the date of April 13, 1891, by Prof. W. Cawthorne Unwin, secretary to the commission, and is herein reproduced (Part I, History, Part II, Detailed Abstracts of Projects, and Part III, Awards and Conclusions) as an historical document of engineering importance.

As a result of the competition, a contract, dated July 14, 1892, was awarded Faesch and Piccard of Geneva, Switzerland, for complete working drawings of a 5000 horsepower turbine including a governor. The contractors sent out Rudolphe Baumann as their engineer to advise in respect of the proposals and of the workshop facilities of American manufacturers and to supervise the construction and installation of the machinery. Traveling and living expenses of the engineer were to be paid by the designers. Guarantees of efficiency, good working order and good speed regulation were included in the contract.

The contract prices were as follows:

Working drawings, supervision and guarantees of efficiency, good working order and good regulation, for two 5000 horse-power units	$6,000
Royalty for use of governor designs	3,000
Third turbine	3,515
	$12,515

Penalties were to be paid as follows:

For every one per cent under a guaranteed efficiency of 75 per cent	$ 125
For failure of turbines and governors to operate in good working order	6,515

(The specifications were met and no penalties were exacted)

Ten turbines were manufactured in America from the Faesch and Piccard designs by the I. P. Morris Company of Philadelphia, and installed in Wheel-pit Number One. The first three governors, however, were made in Geneva by the designers.

When the construction of Power-house Number Two was undertaken, the firm of Escher, Wyss & Company, of Zurich, Switzerland, was commissioned to furnish working drawings for a 5500 horse-power turbine unit. The drawings were subsequently used for the manufacture in America of eleven units which were installed in Wheel-pit Number Two and Nos. 11–21 inclusive. An agreement was made to pay the designers the sum of $2000, and in addition a utilization charge of $1000 for each turbine made from the drawings.

An order dated August 9, 1900, was placed with Escher, Wyss & Company for a new type of oil pressure governor, which had been devised especially for the then unusual requirements of the Niagara development. The cost of the governor was $1600 and of a special oil pump to operate it, $350, f. o. b. Antwerp.

The governor was installed experimentally at unit No. 5 in Power-house Number One in 1901. After it was in successful operation, Escher, Wyss & Company sent out Rudolf Weber, the designer of the governor, to demonstrate its capabilities.

As a result of the experiments, the design was adopted for the eleven units in Power-house Number Two. The experimental governor was installed at unit Number 11 and ten of similar design were made in America for units Nos. 12 to 21. Four smaller governors for the exciter turbines, likewise from an Escher, Wyss & Company design, were also constructed in America.

The original governors in Power-house Number One were replaced in the years 1910–1912 by those of Escher, Wyss & Company design and the same type was adopted for all of the ten units in the Canadian Niagara Power Company plant.

In 1902 an order was placed with Escher, Wyss & Company for three 10,000 horse-power turbines, complete with shafting and governors, erected in the Canadian plant. They were installed as units Nos. 1, 2 and 3. Shortly afterwards rights were acquired to use the Escher, Wyss & Company drawings for the construction, in America, of 10,000 horse-power turbines Nos. 4 and 5, and an order placed for the manufacture of two governors, Nos. 4 and 5, at the Escher, Wyss & Company shops.

Escher, Wyss & Company sent out Herman Prinz to supervise the erection of Canadian units Nos. 1, 2 and 3. He brought three Swiss foremen with him. Their compensation was included in the contract price of the machinery.

Escher, Wyss & Company also furnished a sample bronze turbine runner and cast-iron core box to guide and facilitate the manufacture in this country of the runners for the turbines for Wheel-pit Number Two, two 174 horse-power turbines for driving centrifugal water pumps and also twenty-two high pressure triplex pumps for supplying oil for thrust bearings and for operating the governors.

The centrifugal pumps next above referred to are the Sulzer type and were manufactured in 1903 by Mather and Platt, in Manchester, England.

Other foreign firms which furnished notable material or auxiliary equipment, either directly or through the turbine manufacturers, are:

Skoda Works, Pilsen, Bohemia

Cast steel penstock elbows for units Nos. 1–5 in Canadian plant and two spare cast steel turbine runners for Wheel-pit Number Two.

Societé Anonyme, John Cockerill, Seraing, Belgium

Nickel steel shaft forgings for Canadian units Nos. 1, 2 and 3.

Fried. Krupp, Essen, Germany
Nickel steel forgings and rolled steel tubes for shafting of Canadian units Nos. 4 and 5.

Rheinischer Metallwarenfabrik, Dusseldorf-Reisholz, Germany
Rolled steel tubes for shafting of Canadian units Nos. 1, 2 and 3.

Theodor Horn, Leipzig, Germany
Tachometers for all of the governors in Power-house Numbers One and Two and in the Canadian plant.

The total expenditures in England, France, Switzerland, Belgium and Germany, for engineering fees, machinery and material, resulting directly from the Niagara scientific commission under the presidency of Lord Kelvin, in London, amounted to about $430,000, not including $12,790 paid to French and German engineers for research in electrical reduction and purification of ores and their metals.

Wooden models of the turbines and governors, furnished by Faesch and Piccard, were exhibited by The Niagara Falls Power Company at the World's Fair in Chicago, in 1893, where they attracted much attention and favorable comment.

APPENDIX P

TURBINES AND ALTERNATORS ERECTED IN THE POWER-HOUSES OF THE NIAGARA FALLS POWER COMPANY

Brief Description of Turbines.

Brief Description of Alternators.

Hydro-electric Generating Units of
The Niagara Falls Power Company,
Canadian Niagara Power Company,
in September 1918.

Table Giving Installed Rated Capacity
of Generating Units of The Niagara
Falls Power Company in 1926.

BRIEF DESCRIPTION OF TURBINES
OF
THE NIAGARA FALLS POWER COMPANY

All of 250 revolutions per minute

ORIGINAL TURBINES NOS. 1 TO 10, POWER-HOUSE NUMBER ONE:

Designed by Faesch & Piccard of Geneva, Switzerland. Built by I. P. Morris Company of Philadelphia, Pennsylvania

Were *Fourneyron* type of turbines with two runners, the upper one being inverted. The water was *discharged outward* through the wheels and directly into the wheel-pit. The gates for regulating the speed consisted of cylinders which moved up and down on the outside of each wheel. Water pressure on the upper runner supported a large portion of the weight of the revolving parts of the units, the remainder being carried by a collar thrust bearing. Ice could easily close the small openings in the runners and also the openings in the disc of the upper speed ring, thereby reducing the upward thrust on the upper runner. This compelled the thrust bearing to carry an undue portion of the weight and caused frequent burnouts.

On account of having no draft tubes there was a loss of head equivalent to the distance from the center line between runners to the tail water level.

UNITS NOS. 1 TO 10 (New Turbines Replacing the Original Turbines):

Designed by C. C. Egbert, Mechanical Engineer, The Niagara Falls Power Company and Canadian Niagara Power Company. Built by Bethlehem Steel Company, at Bethlehem, Pennsylvania.

These turbines are the *Francis inward flow type* with a central draft tube discharging directly into the wheel-pit.

The combination roller and oil pressure thrust bearings carry the entire weight of the revolving parts.

UNITS NOS. 11 TO 21, POWER-HOUSE NUMBER TWO:

Designed by Escher, Wyss & Company, of Zurich, Switzerland. Built by I. P. Morris Company of Philadelphia, Pennsylvania.

These turbines are the *Francis inward flow type,* discharging into a draft tube which branches into two sections. These run downward back of the wheel-pit walls and re-enter the wheel-pit at an angle of forty-five degrees.

Balancing pistons on the lower end of the shafts, operating under water pressure, carry a large portion of the weight of the revolving parts of the units and the remainder is carried by oil pressure thrust bearings.

CANADIAN NIAGARA POWER COMPANY

TURBINES 1 TO 3:

Designed and built by Escher, Wyss & Company, at Zurich, Switzerland.

TURBINES 4 AND 5:

Designed by Escher, Wyss & Company, Zurich, Switzerland. Built by I. P. Morris Company of Philadelphia, Pennsylvania.

Turbines 1 to 5 have cylindrical wheel-cases with two runners, the upper one being inverted. These discharge into a common draft chest from which two draft tubes run into the side walls of the wheel-pit and re-enter the pit at an angle of forty-five degrees. A balancing piston located above the wheel-case carries a large portion of the weight of the revolving parts, and the remainder is carried by an oil pressure thrust bearing.

TURBINES 6 AND 7:

Designed by C. C. Egbert, Mechanical Engineer, The Niagara Falls Power Company and Canadian Niagara Power Company. Built by Bethlehem Steel Company at Bethlehem, Pennsylvania.

These turbines were designed to suit the conditions which existed. The wheel-pit had been completed for the installation of units 6 to 11 inclusive, which were to be the same as units 1 to 5 and to give 2500 horse-power more each than those already installed. In order to do this the turbines were built with two spiral wheel-cases. The upper one discharges through the draft tubes which had been built into the wheel-pit walls and the lower one through a center draft directly into the wheel-pit. All the weight of the revolving parts is carried by oil pressure thrust bearings.

TURBINES 8 TO 10:

Designed by C. C. Egbert, Mechanical Engineer, The Niagara Falls Power Company and Canadian Niagara Power Company. Built by Wellman, Seaver, Morgan Company, at Cleveland, Ohio.

These turbines were designed to give the same power as units 6 and 7 and to give greater efficiency by eliminating the double lower penstock elbow where the losses were rather large. The discharge from the single spiral wheel-case is through a draft tube moulded in the concrete arch which spans the wheel-pit and supports the turbine. The weight of the revolving parts is carried in the same way as units 6 and 7.

The speed of all turbines is controlled by cylinder gates located between the runner and the guide vanes. They are moved vertically by the governors located on the generator floor, through series of rods and levers.

Approximate cost of Canadian Niagara Power Company's turbines was as to units

Numbers	*Per horse-power*
1 to 5	$16.20
6 to 7	11.25
8 to 10	11.00

October 13, 1925

BRIEF DESCRIPTION OF ALTERNATORS
OF
THE NIAGARA FALLS POWER COMPANY

All of 25 Cycles, 250 Revolutions per Minute

Alternators 1 to 10—Power-house Number One

Designed and built by Westinghouse Electric and Manufacturing Company of Pittsburgh, Pennsylvania.

External revolving field type which requires large forged nickel steel field rings.
Generate two-phase current at 2200 volts.
Additional data are given in Appendix M.

Alternators 11 to 21—Power-house Number Two

Designed and built by General Electric Company of Schenectady, New York.

Alternators 11 to 16 are the external revolving field type similar to Units 1 to 10.
Alternators 17 to 21 are internal revolving field type which avoids the use of the large steel forging.

Canadian Niagara Power Company

Alternators 1 to 5

Designed and built by General Electric Company.

Internal revolving field type, wound for 12,000 volts, three-phase.

Alternators 6 to 10

Designed and built by Canadian Westinghouse Company of Hamilton, Ontario.

Internal revolving field type similar Units 1 to 5.

October 13, 1925

HYDRO-ELECTRIC
GENERATING UNITS
of
THE NIAGARA FALLS POWER COMPANY
CANADIAN NIAGARA POWER COMPANY

September 20, 1918

Power-house Number One

ORIGINAL UNITS			RECONSTRUCTED UNITS		
Unit No.	*On Commercial Service*	*Rated Power*	*Unit No.*	*On Commercial Service*	*Rated Power*
1	Aug. 26, 1895	5,000		Oct. 8, 1911	5,000
2	Aug. 1895	5,000		Nov. 6, 1911	5,000
3	May 14, 1896	5,000		Dec. 21, 1911	5,000
4	April 26, 1896	5,000		Oct. 21, 1912	5,000
5	Oct. 1, 1898	5,000		Aug. 10, 1912	5,000
6	Jan. 11, 1899	5,000		Dec. 3, 1912	5,000
7	Feb. 13, 1899	5,000		Mar. 3, 1913	5,000
8	Oct. 1898	5,000		April 7, 1912	5,000
9	Feb. 23, 1900	5,000		June 22, 1912	5,000
10	May 24, 1900	5,000		Oct. 28, 1910	5,000

POWER-HOUSE NUMBER TWO

Unit No.	*On Commercial Service*	*Rated Power*
11	Oct. 31, 1902	5,000
12	Nov. 26, 1902	5,000
13	Dec. 4, 1902	5,000
14	Jan. 21, 1903	5,000
15	Feb. 12, 1903	5,000
16	Mar. 20, 1903	5,000
17	Nov. 21, 1903	5,000
18	Nov. 3, 1903	5,000
19	Dec. 9, 1903	5,000
20	Jan. 25, 1904	5,000
21	Mar. 16, 1904	5,000

CANADIAN NIAGARA PLANT

Unit No.	*On Commercial Service*	*Rated Power*
1	July 27, 1905	10,250
2	Sept. 11, 1905	10,250
3	Sept. 27, 1905	10,250
4	April 21, 1906	10,250
5	May 17, 1906	10,250
6	Dec. 6, 1910	12,750
7	July 28, 1913	12,750
8	Sept. 7, 1916	10,750
9	Oct. 22, 1916	10,750
10	Jan. 13, 1917	10,750

The alternators of the above units are of
250 revolutions
25 cycles

INSTALLED[1] RATED CAPACITY OF HYDRO-ELECTRIC GENERATING PLANTS OF THE NIAGARA FALLS POWER COMPANY

September, 1926

NIAGARA POWER-HOUSES	*Water-wheel Rating*	*Generator Rating*
American No. 1	50,000 *h-p.*	38,750 *kw.*
American No. 2	55,000 *h-p.*	41,250 *kw.*
Canadian	121,000 *h-p.*	94,675 *kw.*
Total	226,000 *h-p.*	174,675 *kw.*
HYDRAULIC STATIONS (All American)		
3-A Direct Current	50,000 *h-p.*	41,250 *kw.*
3-A Alternating Current	80,000 *h-p.*	57,600 *kw.*
3-B Alternating Current	112,500 *h-p.*	78,000 *kw.*
3-C Alternating Current	210,000 *h-p.*	156,000 *kw.*
Total	452,500 *h-p.*	332,850 *kw.*
Total Alternating Current	628,500 *h-p.*	466,275 *kw.*
Total Direct Current	50,000 *h-p.*	41,250 *kw.*
Total All Plants	678,500 *h-p.*	507,525 *kw.*

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[1] Installed rated capacity is taken from the name-plate ratings, in some cases the maximum of which the machines are capable is as much as 10 per cent higher than the name-plate rating given in this table.

APPENDIX Q

EXTRACTS FROM "WATER-POWER IN THE BRITISH EMPIRE"

by SIR DUGALD CLERK, *Chairman of the Water-Power Committee*
of the Conjoint Board of Scientific
Societies, London, 1922

APPENDIX

THE FOLLOWING BRIEF EXTRACTS FROM "WATER-POWER IN THE BRITISH EMPIRE," BY SIR DUGALD CLERK, AS CHAIRMAN OF THE WATER-POWER COMMITTEE OF THE CONJOINT BOARD OF SCIENTIFIC SOCIETIES, LONDON, 1922, ARE AUTHORITATIVE AND OF GENERAL INTEREST IN THIS CONNECTION.

The coal position of the world, however, must deteriorate from decade to decade, and it might be of advantage to consider our position in a coalless and oilless world.

The world may be considered as a high solar engine, in which the waters of the seas are evaporated by the heat absorbed, and much of the vapor carried to high levels, at which it is deposited as water and flows down to the sea.

Hydraulic power, in fact, is a form of sun power, and will continue in existence long after the coal and oil in the world have been exhausted.

Coal and oil have also been produced by the action of the great solar engine, and they contain a portion of the energy of radiation of past ages, stored up in the growing wood and leaves of plants, accumulations which are now being rapidly drawn upon by mankind.

Coal and oil are thus the result of past radiant energy, while water and wind are due to present radiant energy. In one case, the store in the earth is being used up and cannot be replaced; in the other case, so long as the solar system lasts, power exists also.

Undoubtedly, as time goes on, hydraulic power must become of increasing importance. In comparing water and heat-engine power it is to be remembered that continuous water-power applied twenty-four hours per day gives three times the energy of heat-engine power at eight hours per day, so that if storage arrangements be successfully applied, one million horse continuous hydraulic power is equivalent to three million steam or other heat-engine power which is available at the estimated fuel cost for eight hours per day only.

The considerations already outlined would indicate that the conservation and utilization of the water-power resources of the Empire is likely to be one of the most important problems in our political economy.

It has usually been understood that the usefulness of a water-supply depends on the possibility of maintaining its uniformity over the whole period of the year, and that the maximum useful power is strictly limited by the minimum power which, by the aid of any suggested storage system, will be available towards the end of the longest probable period of drought.

The main conclusions to be drawn from the evidence available to the Committee, are:

(1) That the potential water-power of the Empire amounts in the aggregate to at least 50 to 75 million horse-power.

(2) That the development of the Empire's natural resources is inseparably connected with that of its water-powers.

(3) That much of this is capable of immediate economic development.

(4) That the developments of such enormous possibilities should not be left to chance, but should be carried out under the guidance of some competent authority.

One of our pressing duties as engineers consists in devoting ourselves to the most serious consideration of applying all possible water-power to supplement the work of coal, and so reduce consumption or increase the utility of our most important asset.

APPENDIX R

NIAGARA POWER CONSIDERED AS PART OF A PROPOSED "SUPERPOWER" SYSTEM

NIAGARA POWER AS A PART OF THE PROPOSED SUPERPOWER SYSTEM FOR THE REGION BETWEEN BOSTON AND WASHINGTON

In the report of 1921, of the United States Geological Survey, regarding a proposed superpower system for the region between Boston and Washington, W. S. Murray, chief of the engineering staff, describes the superpower system, and the power situation on the Niagara River and its relations thereto, in part as follows:

The water that can be diverted at Niagara Falls for the generation of power is now limited by international treaty to 20,000 second-feet on the American side of the river and to 36,000 second-feet on the Canadian side. Practically the whole of this permitted diversion has been made, and no further developments are possible so long as the present treaty is in force. It may be abrogated on one year's notice from either party.

The question of additional diversion of water from the river for power is somewhat complicated with the navigation of Lake Erie, as any large increase in diversion will tend to lower the lake level. By the construction of remedial works at the outlet of Lake Erie, however, it will be practicable to increase the amount of water diverted for power without impairing the navigability of the lake. The scenic beauty of the falls may be preserved by constructing works that will distribute the flow more uniformly over the crest. This power would probably be cheaper to develop than St. Lawrence power and would be equally available for use in the superpower zone.

The superpower system here recommended comprehends a plan of power production that includes the generation of electricity by steam at tidewater and on inland waters where a sufficient quantity of condensing water can be obtained, and also the utilization of all hydro-electric power that may be economically obtainable from rivers within the zone or within transmission distance of it. The electric power so generated will be co-ordinated through a system of interconnected transmission lines, the potentials of which will be on the order of 220,000 and 110,000 volts.

The water powers of Niagara and St. Lawrence rivers are within transmission distance of the superpower zone, but on account of the time required for construction on the St. Lawrence and of the treaty restrictions concerning the use of the water at Niagara Falls the power from these sources has not been considered available in the zone prior to 1930.

Under present construction and operating costs, power purchased at Niagara or on St. Lawrence River at $20 a horse-power, ready for transmission at those points at potentials of not less than 220,000 volts, can be placed at Utica and Schenectady, New York, and at Northampton, Massachusetts, for 4.6 mills per kilowatt-hour, and at Paterson, New Jersey, for 5.7 mills. These figures assume purchases of not less than 300,000 kilowatts delivered at a load factor of not less than 80 per cent.

By the use of Niagara power to the extent of 300,000 kilowatts at a load factor of 80 per cent in the Metropolitan division in 1932 the annual coal requirement will be 1,204,000 tons less than the quantity which would be used were this amount of power generated by new steam-electric plants.

As it will require about eight years to construct the proposed St. Lawrence hydro-electric works and about the same length of time to obtain additional capacity at Niagara Falls that could be released to the superpower zone, the load requirements of 1930 must be met by other facilities. However, if these developments were completed by

1930, the load growth in the Eastern New England, Western New England, and Mohawk-Hudson divisions should be sufficient to absorb the available output of the St. Lawrence by 1932, and that of the Metropolitan division should be sufficient to absorb 300,000 kilowatts at a load factor of 80 per cent from Niagara in the same year. It is believed from consultation with the best-informed authorities on these two projects that power could be purchased from them at not more than $20 per horse-power per year delivered at their bus-bars, and accordingly this figure is used in determining their effect on the cost of power to those divisions of the superpower zone so supplied.

The Metropolitan division by 1932 can absorb 300,000 kilowatts of Niagara power delivered at a load factor of 80 per cent. The cost of this power delivered at Paterson, New Jersey, will be about 5.7 mills per kilowatt-hour. The total cost to the Metropolitan division for the power it will require in 1932, if Niagara power is used, will be $107,651,000. If the growth in energy required between 1930 and 1932 were supplied from new steam-electric plants located in the Metropolitan division, the total cost for power to the division in that year would be $110,899,000, showing a saving of $3,248,000 in favor of Niagara power. Were the power purchased from the Niagara power interests, so that no investment by the superpower system in hydro-electric power-plants at that location would be required, the total added investment for 1932 would be $5,080,000 less than that which would be required if the Niagara power were displaced by steam-electric power.

APPENDIX S

FORTY YEARS OF POWER DEVELOPMENT AND ELECTRICAL DISTRIBUTION FROM THE FALLING WATERS OF NIAGARA BY THE NIAGARA FALLS POWER COMPANY

FORTY YEARS OF POWER DEVELOPMENT AND ELECTRICAL DISTRIBUTION FROM THE FALLING WATERS OF NIAGARA BY THE NIAGARA FALLS POWER COMPANY

The successive incidents during the ten years subsequent to the original incorporation of the so-called Gaskill-Evershed Power Company,[1] and for twenty-two years thereafter, are briefly suggested as follows:

1886	Evershed power project announced and "Gaskill" company formed.
1887	Public offering of capital stock, without success.
1888	Prospectus prepared for bond issue, in London, but not issued.
1889	Subscription invited for capital, without avail, and optional contract made for sale of company.
1890	Sale of company concluded to New York capitalists.
1890	International Niagara Commission organized June 21, to conduct a scientific symposium on the development of power at Niagara Falls.
1891	Niagara power project formulated, central power station adopted December 14, for generation and distribution of energy by electricity or by compressed air, and general construction commenced.
1892	Hydraulic system adopted, with central power station and 5000 horse-power turbines under contract.
1893	Tunnel completed and alternating current adopted May 6; contracts for alternators signed October 26.
1894	Turbines installed and alternators under construction.
1895	Alternators installed and hydro-electric units of 5000 horse-power put into commercial operation August 26.
1896	Three alternators (15,000 horse-power total) in operation and electric power delivered in Buffalo, beginning November 15.
1897	Provision for additional alternators to meet increased demand of chemical and metallurgical industries.
1898	Construction of duplicate wheel-pit slot commencing for Power-house Number Two for 50,000 horse-power development.
1900	Principal works completed and ten alternators of 5000 horse-power each in service in Power-house Number One.
1902–1904	Power-house Number Two completed; 55,000 horse-power.
1905–1906	Canadian plant constructed with 51,250 horse-power.
1910–1913	Efficiency of Power-house Number One increased by reconstruction of hydraulic units with Francis-type inward-flow turbines.

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[1] Niagara River Hydraulic Tunnel, Power and Sewer Company.

NIAGARA POWER

1910–1917 Rated capacity of Canadian Power-house increased by 57,750 horse-power to a total of 109,000.

1918 31 hydro-electric units in three power stations total capacity 214,000 horse-power.

1918 Consolidation of power companies.

1924 12,000 horse-power turbine added to Canadian plant.

1926 Installed capacity of all power-houses, including those of Schoellkopf companies 678,500 horse-power.

APPENDIX T

POWER STATISTICS OF UNITED STATES AND OF NEW YORK

Compiled from data issued by the Division of Power Resources of the United States Geological Survey and from the census of Electrical Industries, 1922, Central Electric Light and Power Stations issued by the Department of Commerce

POWER DEVELOPED AT NIAGARA FALLS, 1921

The plants near Niagara Falls together form the largest water-power development in the world.

At Niagara Falls, on Niagara River, which connects lakes Erie and Ontario, there is the finest power site in North America. Here are combined a high head that is easily developed, a large uniform flow, and a market for the power. The unique scenic beauty of the falls has prevented the complete utilization of the site, but the plants in operation have a capacity of 870,000 horse-power, of which 385,500 horse-power is on the United States side. The power actually developed amounts to about 700,000 horse-power. To this total should be added 12,000 horse-power developed on the Welland Canal and 42,000 horse-power developed at Decew Falls, 2 miles from St. Catharines, Ontario, from water diverted from the Welland Canal over the Niagara escarpment. A license has been granted by the Federal Power Commission that will increase to 500,000[1] horse-power the installed capacity on the United States side of Niagara River. The Hydro-electric Power Commission of Ontario is now constructing an additional plant at Niagara Falls which will have an initial capacity of 300,000 horse-power and an ultimate capacity of 540,000[1] horse-power. The water is to be carried 12 miles through a canal and used with an effective head of 305 feet. A large part of the power at Niagara Falls is obtained from plants operating at heads of less than 200 feet, though the difference in level between lakes Erie and Ontario is 327 feet. If the total flow of the river were used the falls would furnish, under favorable conditions, about 6,000,000 horse-power. A plan whereby 60 per cent of the total flow of the river can be diverted for developing power is being considered.

EXCERPT FROM "WORLD ATLAS OF COMMERCIAL
GEOLOGY, PART II, WATER-POWER OF THE WORLD,"
PUBLISHED BY UNITED STATES GEOLOGICAL
SURVEY, 1921

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[1] These developments substantially completed by 1926.

PRODUCTION OF ELECTRIC POWER BY PUBLIC UTILITY PLANTS IN THE UNITED STATES

1920–1925

Years	*United States*	*New York State*	*Per cent of U S. Total produced by water-power and fuel*	*N. Y. Per cent of U. S. Total*
1925	*Kw-h.*	*Kw-h.*		
Water-power	22,355,917,000	4,484,970,000	33.9	20.06
Fuels	43,514,389,000	5,781,730,000	66.1	13.29
Totals	65,870,306,000	10,266,700,000	100	15.58
1924				
Water-power	19,969,463,000	3,961,177,000	33.8	19.84
Fuels	39,044,127,000	5,327,392,000	66.2	13.64
Totals	59,013,590,000	9,288,569,000	100	15.74
1923				
Water-power	19,615,701,000	3,560,816,000	35.1	18.15
Fuels	36,312,155,000	5,160,374,000	64.9	14.21
Totals	55,927,856,000	8,721,190,000	100	15.59
1922				
Water-power	17,206,465,000	2,951,818,000	36.1	17.15
Fuels	30,452,539,000	4,468,960,000	63.9	14.68
Totals	47,659,004,000	7,420,778,000	100	15.57
1921				
Water-power	14,970,408,000	2,203,564,000	36.5	14.72
Fuels	26,005,209,000	3,967,142,000	63.5	15.27
Totals	40,975,617,000	6,170,706,000	100	15.06
1920				
Water-power	16,149,709,000	3,029,623,000	37.1	18.76
Fuels	27,405,171,000	3,909,419,000	62.9	14.26
Totals	43,554,880,000	6,939,042,000	100	15.93

PER CENT OF PRODUCTION OF ELECTRIC POWER

In the United States and in the State of New York from Water-power and Fuels in Yearly Periods for Six Years, 1920–1925

Years	*United States*		*New York State*	
	Water-power (Per cent)	*Fuels (Per cent)*	*Water-power (Per cent)*	*Fuels (Per cent)*
1925	33.9	66.1	43.7	56.3
1924	33.8	66.2	42.6	57.4
1923	35.1	64.9	40.8	59.2
1922	36.1	63.9	39.8	60.2
1921	36.5	63.5	35.7	64.3
1920	37.1	62.9	43.6	56.4

STATE OF NEW YORK

Annual Production of Electricity by Use of Water-power

1920–1925

Years	*Kilowatt-hours*	*Per cent of Total State Production from Water-power*	*Per cent of Total United States Production by Water-power*
1925	4,484,970,000	43.7	20.06
1924	3,961,177,000	42.6	19.84
1923	3,560,816,000	40.8	18.15
1922	2,951,818,000	39.8	17.15
1921	2,203,564,000	35.7	14.72
1920	3,029,623,000	43.6	18.76

NEW YORK'S RELATIVE PROPORTION OF ELECTRIC POWER PRODUCED BY PUBLIC UTILITY PLANTS IN THE UNITED STATES

1920–1925

(Condensed from table on page 460)

Years	*United States Kw-h.*	*New York State Kw-h.*	*N. Y. Per cent of U. S. Total*
1925	65,870,306,000	10,266,700,000	15.58
1924	59,013,590,000	9,288,569,000	15.74
1923	55,927,856,000	8,721,190,000	15.59
1922	47,659,004,000	7,420,778,000	15.57
1921	40,975,617,000	6,170,706,000	15.06
1920	43,554,880,000	6,939,042,000	15.93

ANNUAL CONSUMPTION OF COAL

In the Production of Electrical Power in the United States and in the State of New York

1920–1925

	Short Tons		
Year	*United States*	*New York State*	*Per cent of U. S. Total*
1925	40,222,006	5,030,541	12.51
1924	37,556,000	4,949,267	13.18
1923	38,954,005	5,067,313	13.04
1922	34,178,907	4,643,268	13.58
1921	31,585,284	4,392,482	13.91
1920	37,123,855	4,747,709	12.78

APPENDIX

ANNUAL CONSUMPTION OF COAL

In Production of Electricity

ELECTRIC POWER PLANTS CONSUMED NEARLY 1½ TONS OF COAL EACH SECOND IN 1925

The amount of coal consumed in producing electricity in 1925 was only 7 per cent greater than in 1924. The amount of oil was 38 per cent less and the amount of gas was 4 per cent less than in 1924. Although the oil consumed amounted to more than 10 million barrels and the gas to nearly 50 billion cubic feet, coal represented nearly 90 per cent of all the fuel used by electric power-plants. The coal plus the coal equivalent of the oil, gas, and wood used in the generation of electricity by public-utility plants in 1925 amounted to about 45,000,000 tons, or an average of nearly 3000 pounds a second or 100 carloads an hour throughout the year.

The following figures of consumption of coal and its approximate equivalents in other fuels, 1919–1925 are upon the basis of

1 ton of coal = 4.2 barrels of oil = 22,000 cubic feet of gas
1 horse-power = .746 kilowatt of electricity

Pounds of coal used per kilowatt hour produced

Year	*Pounds of Coal*
1925 =	2.1
1924 =	2.2
1923 =	2.4
1922 =	2.5
1921 =	2.7
1920 =	3.0
1919 =	3.2

This record indicates an improvement in the efficiency of steam engines in the use of coal of 26 per cent in six years.

The total annual output of electricity by public utility power-plants in 1925 was 65,801,000,000 kilowatt-hours, an increase of 11.5 per cent over the output for 1924. Of this quantity, 33.9 per cent was produced by the use of water-power, a slight increase over the percentage of 1924. It would have required the consumption of 23,000,000 tons of coal to generate this per cent. More electricity was generated for public use by public utility power-plants in the United States in December, 1925, than ever before in one month, the total being 6,108,000,000 kilowatt-hours for the month.

The gain in the efficiency of fuel continued in 1925, as there was a decrease of about 0.1 pound in the average consumption of coal per kilowatt-hour, compared with the rate of 1924. This apparently small gain amounts to more than two million tons of coal for the year.

PRODUCTION OF ELECTRIC POWER BY PUBLIC-UTILITY POWER-PLANTS IN THE UNITED STATES

FOR 1926

Compiled by Divisions of Power Resources, Geological Survey,
Under the Direction of A. H. Horton

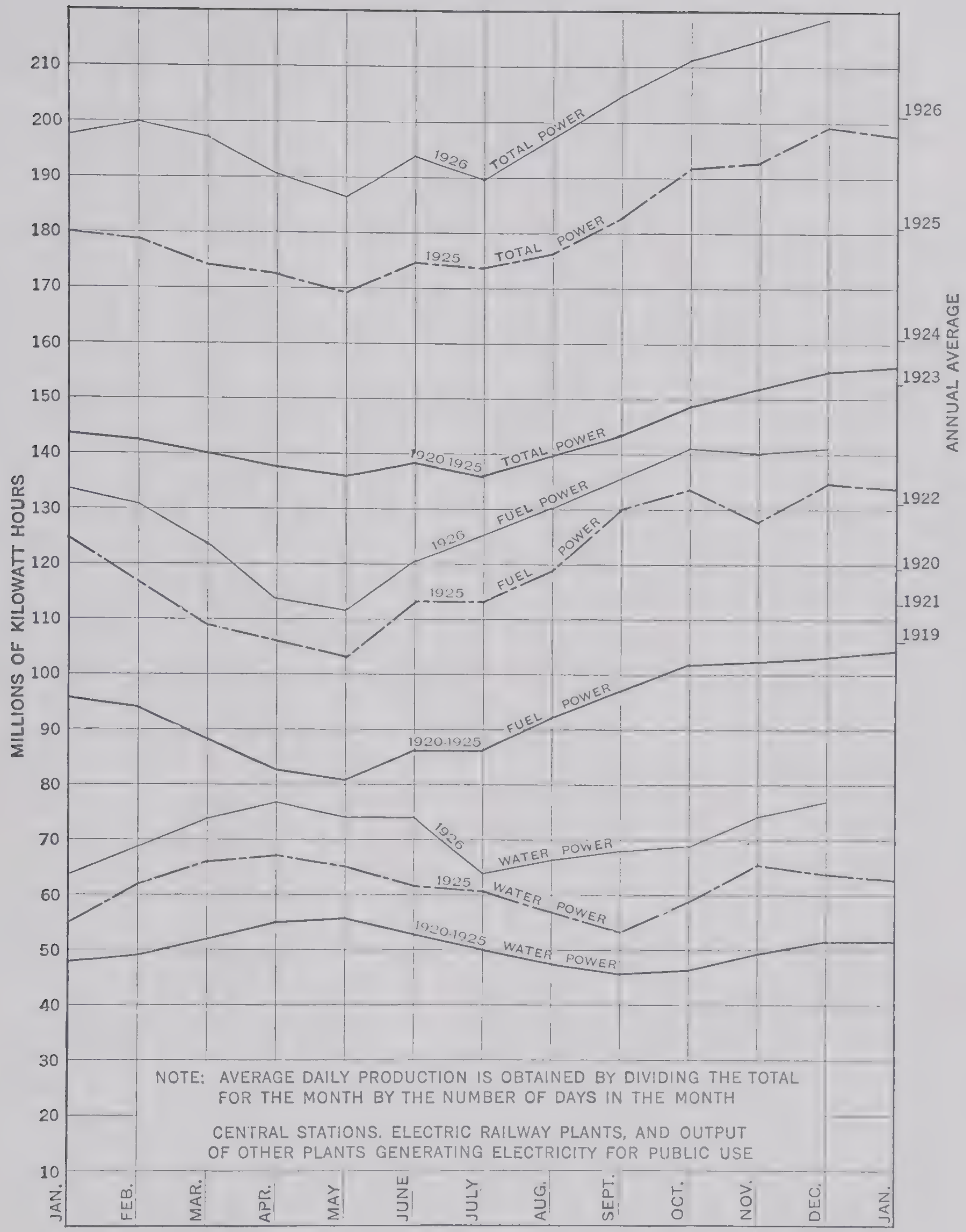
Total monthly production of electricity by public-utility power-plants in 1925 and 1926

	1925	1926	*Per cent Increase* 1926	*Produced by Water-power, per cent*	
				1925	1926
January .	5,573,000,000	6,121,000,000	10	30	32
February .	5,001,000,000	5,602,000,000	12	35	34
March . .	5,392,000,000	6,149,000,000	14	38	37
April . .	5,181,000,000	5,773,000,000	11	39	40
May . .	5,240,000,000	5,809,000,000	11	39	40
June . .	5,246,000,000	5,879,000,000	12	35	38
July . .	5,389,000,000	5,917,000,000	10	35	34
August .	5,465,000,000	6,145,000,000	12	32	34
September	5,495,000,000	6,180,000,000	12	29	33
October .	5,949,000,000	6,555,000,000	10	30	33
November.	5,786,000,000	6,450,000,000	11	34	35
December .	6,153,000,000	6,767,000,000	10	32	35
	65,870,000,000	73,347,000,000	11	34	35

The curves on page 465 show by months the average daily production of electricity for 1925, 1926, and the six-year period 1920 to 1925.

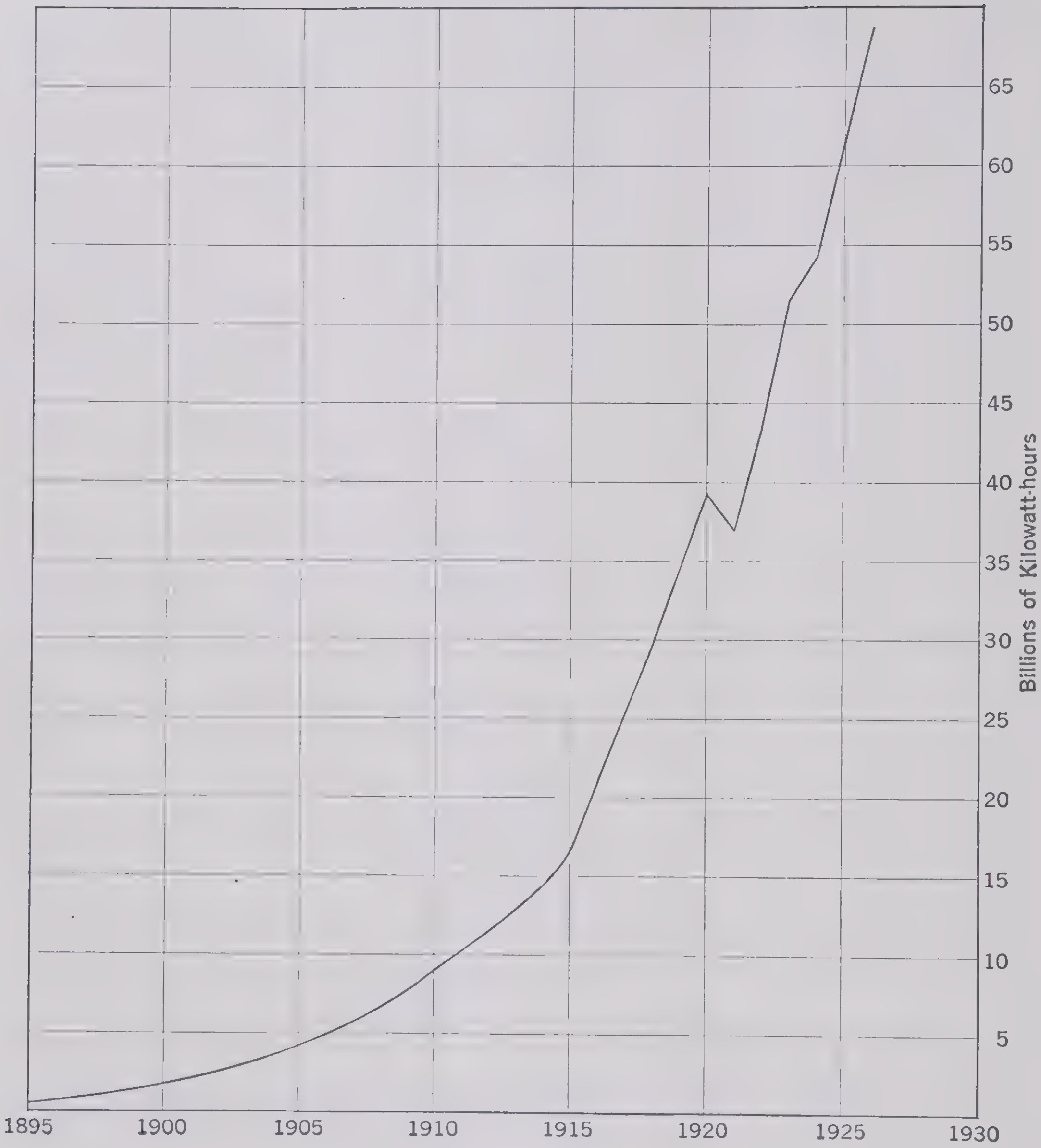
The total output for 1926 was 73,347,000,000 kilowatt-hours, an increase of about 11 per cent over the total output for 1925. The proportion of the total output produced by the use of water-power was 35 per cent, 1 per cent larger than in 1925.

The quantities given are based on the operation of all power-plants producing 10,000 kilowatt-hours or more per month, engaged in generating electricity for public use, including Central Stations and Electric-Railway Plants. Reports are received from plants representing over 95 per cent of the total capacity. The output of those plants which do not submit reports is estimated; therefore the figures of output as reported are on a 100 per cent basis.



Electrical Energy Produced by Central Power Stations in the United States

The curves show an approximate doubling of output every five years or a sixty-four fold increase in the thirty-two years since The Niagara Falls Power Company began operation in 1895, inaugurating the large scale use of polyphase alternating current. All of the electrical energy now generated with the exception of a few per cent is by the system adopted at Niagara



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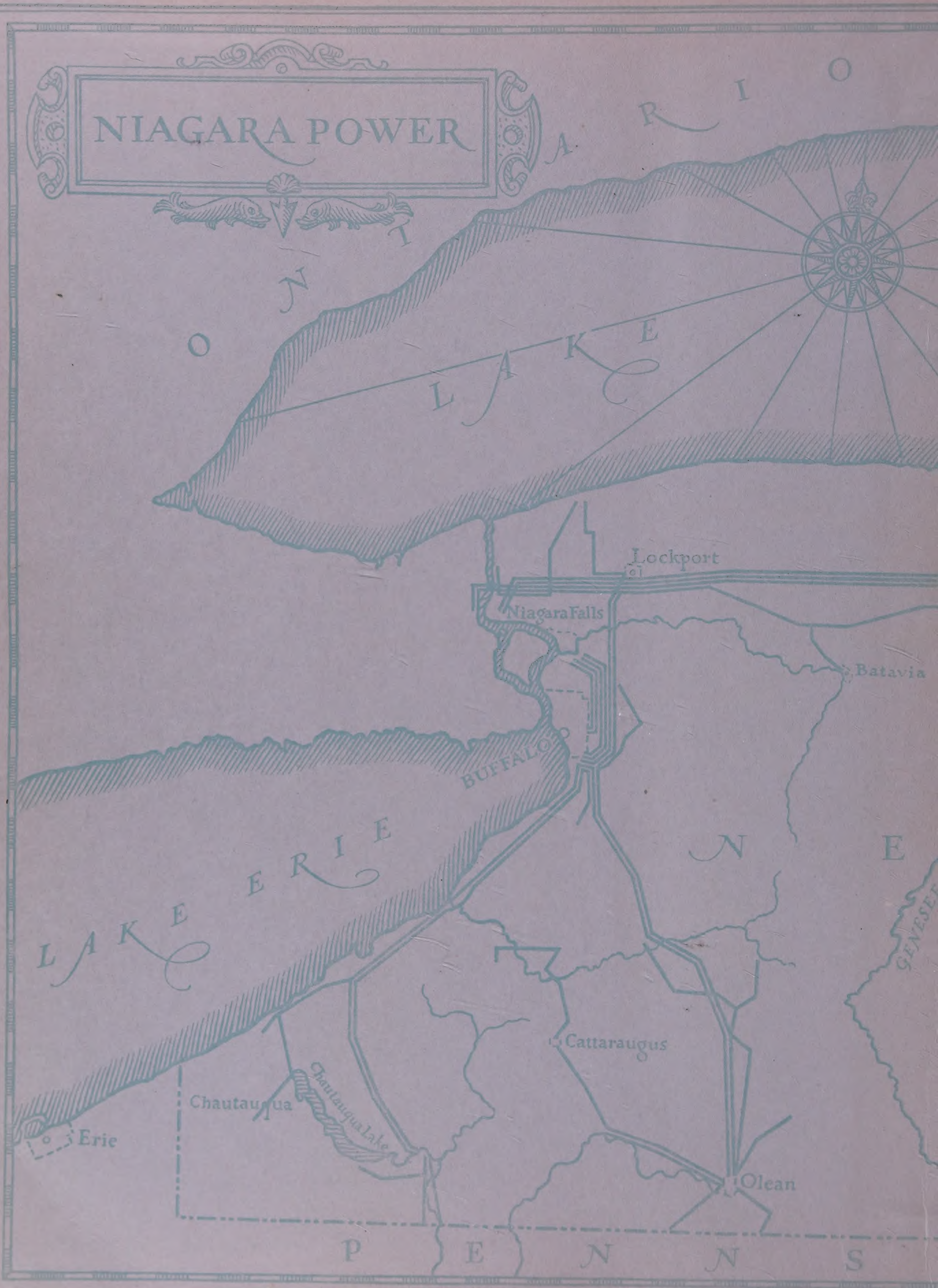
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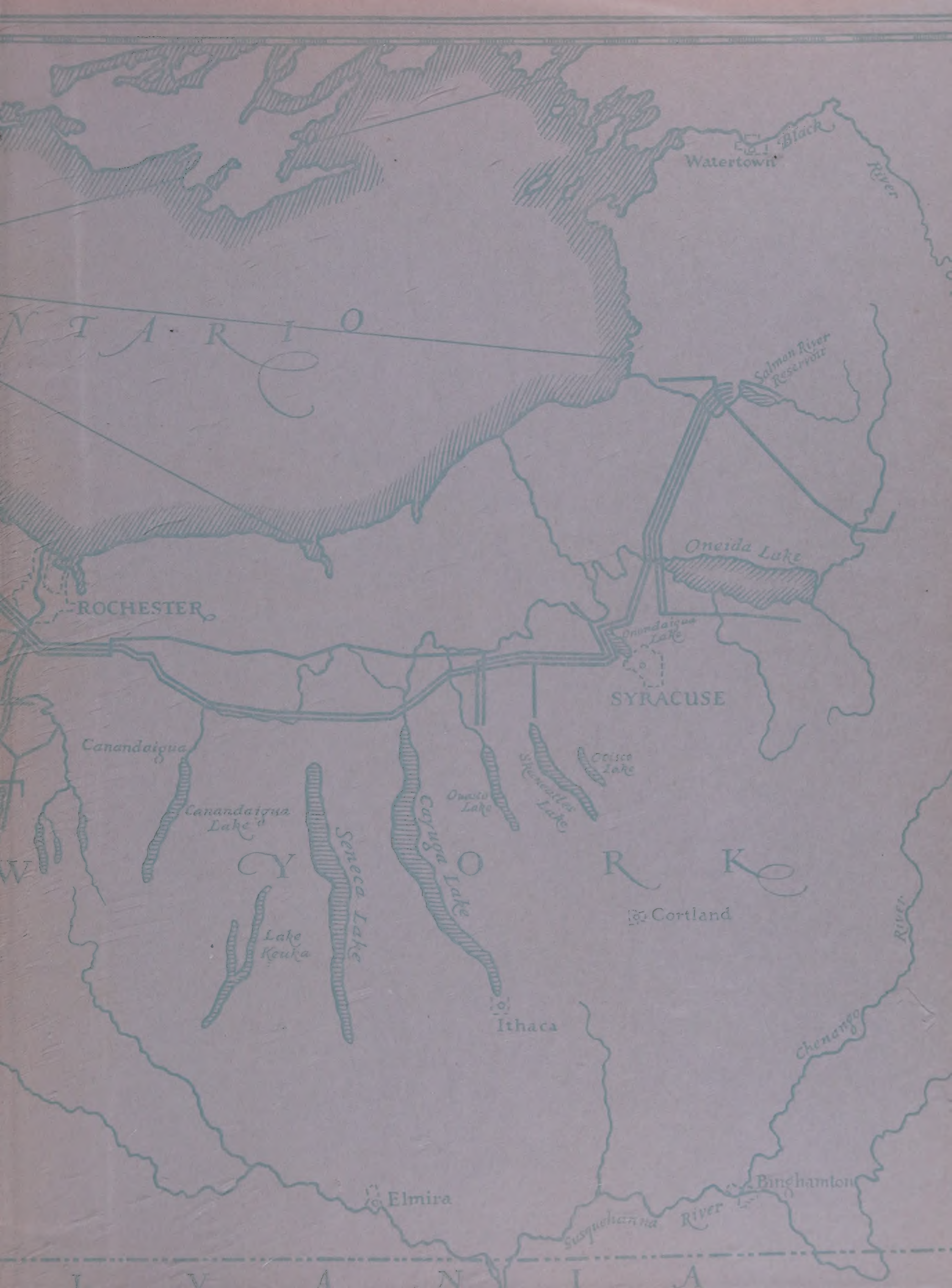
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